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Monitoring Forest Activities Using JERS-1 Spaceborne SAR in the Province of Aurora, Philippines: Relationship Between Forest Density and RADAR Backscatter

By

Jose C. Cabanayan Jr.

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A thesis submitted to the Faculty of Graduate Studies and Research in partial fulfillment of the requirements for the degree of Master of Science

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Abstract

Monitoring tropical forests in the Philippines, especially illegal harvesting and land clearing, can not be accomplished using optical remote sensing because of cloud cover and haze. Imaging RADAR systems provide data on forest characteristics through clouds and haze. The objective of this study was to determine the relationship between forest density and RADAR data values using JERS-1 satellite data for Aurora province.

The RADAR data were sampled for areas of various forest density, from existing vegetation maps, and slope characteristics derived from a digital elevation model. An analysis of variance was performed to test for significant differences in RADAR data values for different combinations of forest density with slope magnitude and aspect.

There are some significant differences in RADAR values among the forest density classes. However, the local topography influences the RADAR values significantly which masks some of the forest density information. Forest monitoring would be difficult to undertake using the JERS-1 SAR data alone. This study has shown that slight changes in forest density cannot be easily differentiated. It may be possible to identify land clearing activities more easily as the forest is totally removed and differences are significant between open areas and grassland areas and various forest classes.

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Chapter 1. INTRODUCTION

1.1 Background

The Philippines form an archipelago of 7,100 islands with a total area of 30 million hectares (Figure 1). After the second World War, the Philippine tropical forest was intact and many Filipinos believed that this natural resource would remain inexhaustible. However, the damage inflicted on the various infrastructures by the war accelerated the cutting down of virgin forest, and was followed by rapid development of forest based industries, mainly logging (Diaz 1982). What was labeled as "inexhaustible" was reduced by 50% in only 20 years from 1968 to 1988. A mere 8 million hectares of forest existed at the last national forest inventory in 1988, compared to an estimated forest area of 16 million hectares reported in the first national forest inventory in 1968 (Atienza 1988). This dramatic decrease in the forest area is very disturbing not only to forest managers, but to the general population as well.

The Department of Environment and Natural Resources (DENR) is assigned the task to undertake the management of the natural resources of the Philippines, including the forest. The DENR is often accused of not protecting the environment for the reason that ongoing forest denudation does not appear to be controlled. In response to this criticism, major policy reforms were instituted by the DENR, including a log export ban and reduction of timber license holders to a selected few. From the more than 100 timber license agreements (TLA's) operating in the country before 1991, only 30 TLA's remained after policy reforms where logging in the virgin or old growth forest was banned. However, logging has been allowed to continue in the residual forest which is at

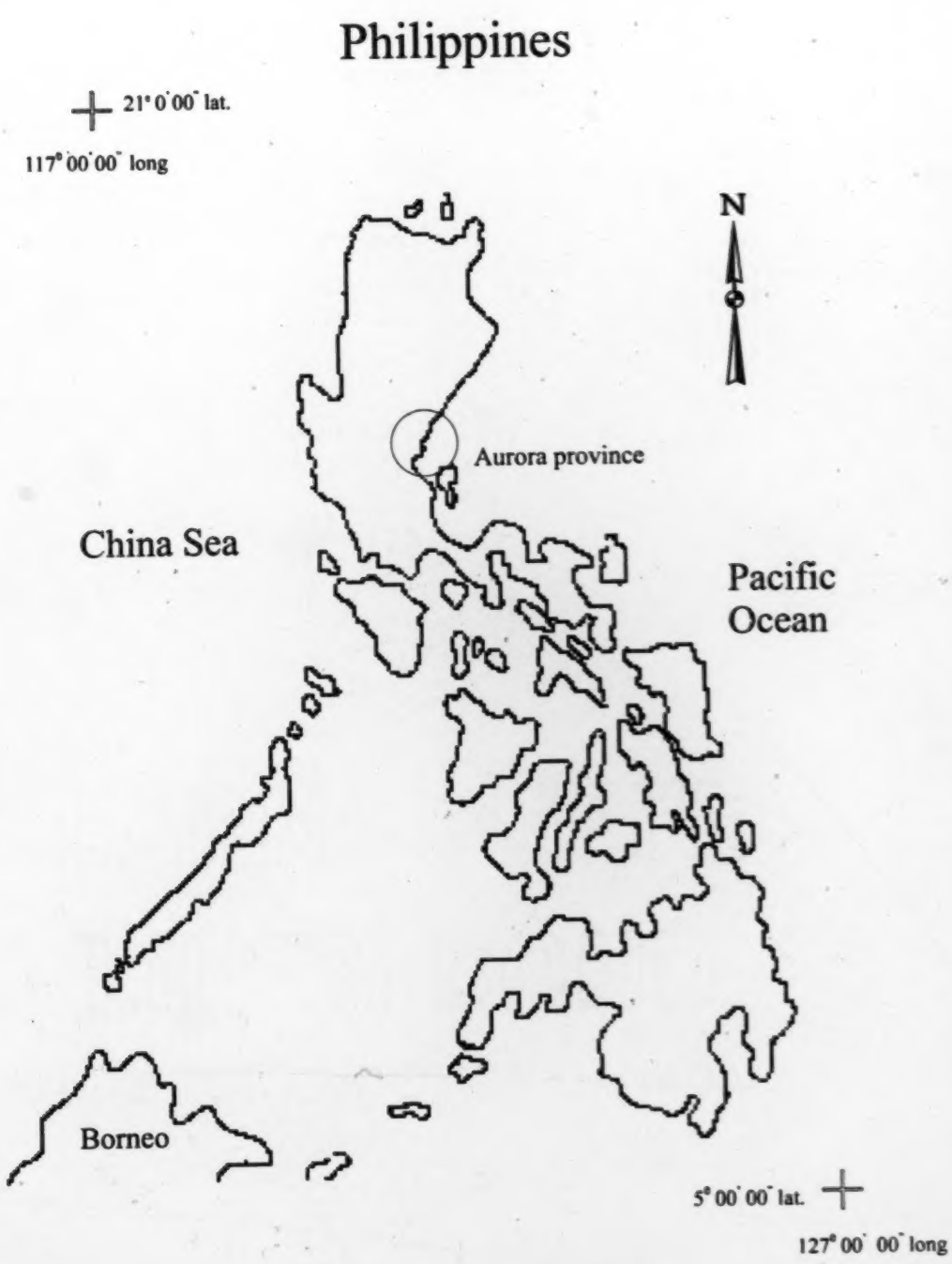


Figure 1. Map of the Philippines with the location of Aurora province.

least 25 years of age and contains enough volume, as determined by the DENR (FAO 1993). As early as 1910, when logging was already considered destructive, an American forester named Barrington Moore, noted the more destructive nature of the practices of shifting cultivation (kaingin), or sometimes referred to as "slash and burn" farming (Tucker 1992). In addition to the slash and burn farming still practiced today, with its resulting increased susceptibility of soils to erosion and reduced air and water quality, logging without government permits has also become prevalent. The reduction in the legal timber supply due to the reduction in licensed timber holders, pressures for poverty alleviation, and the need for raw materials for furniture making, have forced people back to the forest and led to this increase in illegal logging.

Illegal logging and other illegal forest activities are some of the main problems that have gone unchecked. The situation has been aggravated by the fact that the DENR does not even have a reliable and immediate monitoring capability in hand. Being responsible for forest management, the DENR, is monitoring all existing forest activities. This job is not easy since most of the areas with forest cover are sometimes inaccessible and difficult to visit through conventional means, either by vehicles or by foot. Aerial photography and aerial reconnaissance is being used, but eventually becomes very expensive due to the need for reflights because of the area in the forest is often cloudy or hazy, typical in the tropical forest.

A potential cost effective alternative to airborne investigations is the use of satellite remote sensing such as LANDSAT and SPOT data which are commercially available. However, the data from these optical instruments are significantly affected by atmospheric conditions as they recorded intensities of reflected sunlight from terrain

features and are therefore difficult to use in tropical environments because of perpetual cloud cover (Lillesand and Kiefer 1994).

To effectively monitor and prevent further forest destruction, there is a need for a more accurate system that is independent of the cloud cover conditions. A very important development in recent years is the RADAR imaging technology. The use of selected microwave frequencies for imaging RADAR, in the mapping and monitoring of changes in the earth's surface, is relatively new compared to the use of visible and reflected infrared frequencies and optical imaging techniques, such as aerial photography or satellite imagery from the LANDSAT or SPOT systems. The imaging RADAR is more difficult to understand because the images produced are not recorded as normally observed by the naked eye or by an optical instrument. In RADAR imaging, a pulse of energy of selected frequency, polarization, and incidence angle, is transmitted from the system to the ground and the strength of the energy scattered back to the system is recorded (Lillesand and Kiefer 1994). Backscattering is influenced primarily by terrain roughness and electrical characteristics - dielectric constants, of terrain features. Compared to optical instruments, imaging RADAR posses certain advantages, primarily the ability of the energy at microwave frequencies to penetrate both clouds and haze, as well as, a vegetation canopy. The information content of the RADAR image is different but complimentary to that of optical imaging systems. Therefore, the RADAR data may provide additional information compared to the use of the optical image alone.

The inherent advantages of the imaging RADAR makes it potentially useful for monitoring different forest activities in the tropical forest of the Philippines where the use

of optical instruments is ineffective. The imaging RADAR data have three characteristics which make them different from other satellite data:

1. Depending on the single wavelength employed, the microwave energy transmitted by the RADAR, to a large extent penetrates into the canopy, and much of the backscattered energy detected is a result of the interactions above the ground surface.
2. The reflection of the microwave energy from the vegetated terrain is highly dependent on the water content of the vegetation and surface layers. The presence and/or absence of these layers significantly alters the energy detected by the RADAR antennae. and;
3. The third important characteristic is its ability to operate independent of cloud cover and solar illumination. These systems can collect imagery during periods of rain, cloud and smoke cover which is not possible with visible and near infrared spectrum sensors.

Synthetic Aperture RADAR (SAR) data have been very effective in the monitoring and mapping of clearcuts and forest regeneration, forest infrastructures and other developments that occupy large and contiguous areas (Herman *et al.* 1995). Research projects on the use of RADAR data, however, are mostly done in the temperate countries where there are large tracts of monocultures of conifers and hardwoods, and the logging practice of clearcutting is common (Wilson 1996, Yatabe and Leckie 1995). The results of this research, however, are difficult to implement in the tropical forest where there is greater diversity in the tree species composition, tree density, selective logging

practice, and management. In addition, only small contiguous areas are affected at any one time due to the rough topography.

1.2 Objectives and Hypothesis

Illegal logging is done with selective cutting and removal of the trees that are suitable mostly for furniture making, primarily Narra (*Pterocarpus indicus*), Ipil (*Intsa Bijuga*), and Red Lauan (*Shorea polysperma*), or construction materials, primarily trees with diameter at breast height greater than 40 centimeters. This selective removal reduces the crown canopy and thereby decreases the forest density, which could possibly be detected with the use of RADAR data. The main goal of this research was to evaluate the use of the L-Band RADAR imagery collected by the JERS-1 satellite, for monitoring different forest activities in the province of Aurora, particularly in the Aurora National Park, but with a view for application to the whole country. To achieve the goal for this study, two specific objectives are addressed:

1. To determine if there are differences in RADAR backscatter from areas of different forest densities in the rough terrain of Aurora province and,
2. To determine the contribution of the terrain aspect and slope classes to backscattered energies for each of the individual forest densities.

The hypothesis is that differences in the RADAR image gray level values exist among selected forest density classes. Furthermore, the effect of slope magnitude and aspect on RADAR image gray level values for the forest density classes, will be explored.

1.3 Study Area

The province of Aurora is located in the mid-eastern coast of Luzon island bounded by the provinces of Isabela and Quirino in the north, Nueva Viscaya and Nueva Ecija in the west, Quezon in the south, and the Pacific ocean on the east (Figure 2). The total area of the province is 309,366 hectares with approximately 227,000 hectares of forest cover or 73% (NEDA 1989).

The study area is located in the province of Aurora, a narrow strip of land that rises abruptly towards inland from the east and facing the Pacific ocean (Figures 1 and 2). The study site is in the mid portion of the province, and is located within four municipalities: Dipaculao, Maria Aurora, Baler (also the capital) and San Luis. They are not equally represented within the study area, but comprise more than 65% of the total population of the whole province. The initial size of the study area was 38 x 36 kilometers. This was reduced slightly for the analysis because of the areal coverage by the vegetation map information. The northern most portion is located at 1 752 600N, south at 1 714 300N, east at 348 800E and to the west is 312 700E in UTM zone 51, over the Luzon grid. This is one of the few remaining provinces in the Philippines where the forest still occupies more than half of the total land area. Diverse forest activities are found including protected areas as national parks, watershed reservations, and regulated areas of logging concessions, and pasture. As the population of the province and its neighbors continues to grow, so does the pressure on the forest as illegal logging by the natives and slash and burn farming cannot be contained. Trees are cut selectively by size and species suitable for furniture and construction and processed into squared logs for transport under the shade of the forest canopy (Bueno 1987).

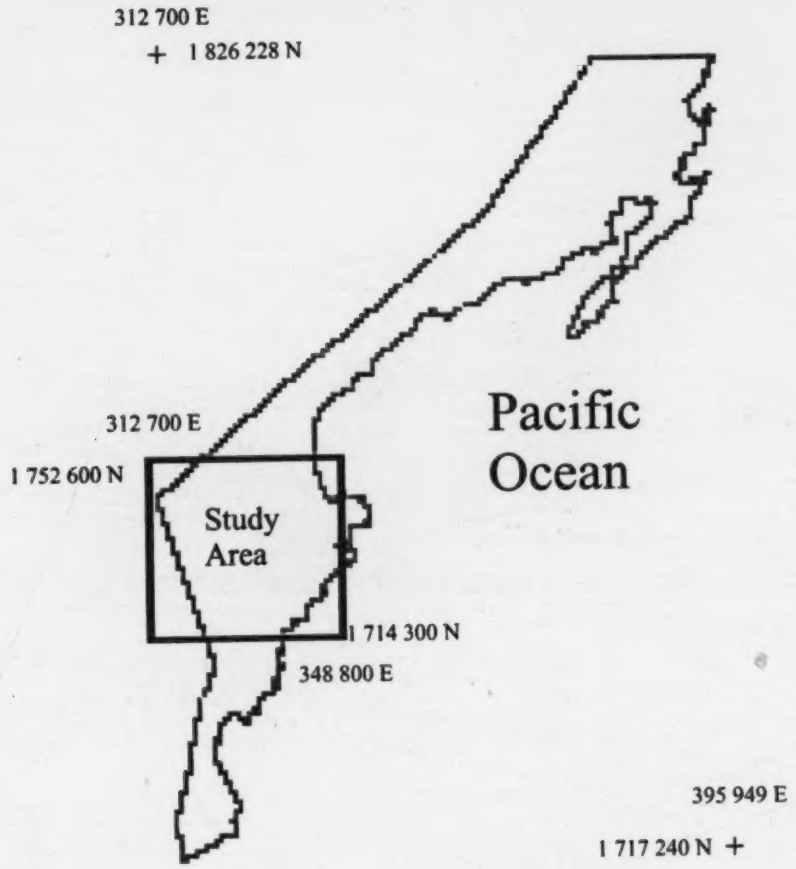


Figure 2. Map of Aurora Province showing the location of the study area with UTM northings and eastings (UTM zone 51).

1.3.1 Topography

The province lies in the Sierra Madre mountain range, where 78% of the area is considered upland with elevation over 100 meters above mean sea level (amsl). The area is generally mountainous to rolling (AIADP 1989). Since the study area is bounded by the Pacific ocean to the east, its lowest elevation is sea level. The highest elevation is at 1,885 meters amsl in the southern portion of the area.

1.3.2 Climate

The entire province of Aurora falls within the Type IV climate of the Corona's classification (AIADP 1989). It is characterized by more or less evenly distributed precipitation throughout the year with no distinct wet and dry season. The average number of rainy days per month is 16 days, or if evenly distributed, it rains every other day. The average temperature is 36.7 degrees Celsius and relative humidity is 82%. The prevailing wind direction is from the east, and the site is affected by typhoons up to four times annually (AIADP 1989, BSWM 1989).

1.3.3 Soils and drainage

The recent Land Capability and Soil Taxonomic Study conducted by the Bureau of Soil under the Department of Agriculture (1986) has divided the province into five pedo-ecological zones based on soils and the bio-physical characteristics of the land, such as the slope, temperature, and elevation. In the study area, the following (Table 1) is the breakdown of the area distribution according to the five different zones (BSWM 1986):

Table 1. Proportions of Aurora Province, the Philippines, in different pedo-ecological zones (BSWM 1986).

Pedo - ecological zones	% Area
Warm lowland	14.4 %
Warm cool upland	12.3%
Warm cool hilly	26.5%
Cool highland	44.2%
Miscellaneous area	2.6%

1.3.4 Forest and vegetation

There are two main land uses in the province : forest land and the extensive/ intensive agriculture production. Forest lands include:

1. Mossy forest
2. Dipterocarp forest
3. Residual forest
4. Sub-marginal forest
5. Brushland
6. Mangrove forest

The last class does not exist substantially in this specific study area. Additional classes of grassland and open land are included in the study area for identification. The extensive/intensive land use of agriculture was not included for the study because the primary interest was only on the relationships between the degree of RADAR backscatter

from forest areas. Brief descriptions of each of the included land use classes follow (NFRI 1988):

Mossy Forest - Tropical rain forest of high elevations, usually in the 1,000 + meter above mean sea level. Dominated by *Podocarpaceae, Myrtaceae* and *Fagaceae* having short boled trees of medium height up to about 5 meters, and covered with epiphytes and moss. These areas have a finer texture when observed on an aerial photographs than the Dipterocarp species. Humidity is mostly high and numerous creeks originate from the area.

Dipterocarp Old Growth Forest at Low Altitude -Tropical rainforest predominantly stocked with mature trees belonging to the *Dipterocarpaceae* family and usually located in areas of an altitude of 800 meters and lower. This class is comprised mainly of species belonging to the *Shorea* and *Parashorea* genera. When fully grown, these trees reach a height of 30 meters.

Dipterocarp Old Growth Forest at High Altitude - Tropical rainforest that are predominantly stocked with mature trees of the *Dipterocarpaceae* family . They are found at elevations above 800 meters in areas with no traces of commercial logging. They are easily recognizable on aerial photographs by the large, compact and coarse textured canopy. While similar in structure to the Dipterocarp Old Growth in low altitude, the total volume is significantly lower (NAMRIA 1991).

Residual Dipterocarp Forest - Tropical rain forest dominated by the *Dipterocarpaceae* family after commercial logging. It is recognized by having lower stand height and a fine textured canopy on aerial photographs. The presence of logging roads can be detected in areas of commercial logging. Forest density is low due to felling and the areas are usually found at lower elevation than the Old Growth Forests.

Sub marginal Forest - Forest with generally the same species as Dipterocarp forest but with restrained growth due to poor soil conditions (shallow or poorly drained), calcareous and windy weather conditions. It is identified as having a finer texture on aerial photographs compared to the Dipterocarp trees.

Brushland - Degraded secondary forests dominated by discontinuous forest cover and shrubby vegetation. Areas are overlogged and the main Dipterocarp species are mostly gone and replaced by secondary legume species. Tree heights reach 15 meters.

Grassland- Areas that are devoid of forest vegetation and brush. They are covered with grasses, primarily *Imperata cylindrica (*cogon*)*. Some of these areas are the result of over-use due to shifting cultivation practices and have been left to natural regeneration.

Open land- Areas that are barren and rocky and lack vegetation. They are exposed to wind and other forms of erosion. Also included in this class are river beds, beaches, and collapsed areas formed by land slides.

Chapter 2. REVIEW OF LITERATURE

2.1 Introduction

Large, relatively inaccessible forested areas are prime targets for studies on the application of remote sensing to forest resource inventory and monitoring. As described in the introduction, some of the unique problems of forest monitoring occurring in the Philippines may be solved through the application of satellite RADAR imaging techniques, once the relationships between the satellite data and forest characteristics are understood.

The advantage of imaging objects without relying on the sun's energy is an important characteristics of the RADAR imaging technique. It has been recognized to be an alternative to aerial photographs in providing images of the earth's surface (Trevett 1986). The difference between a photograph, and a RADAR image though, is that the image produced from the latter is not the same as one produced from an optical camera. Photographic images are records of solar reflectance. They are easily understood because the subject has been studied for many years, and the information is captured in a way similar to the way in which the human eye perceives objects. The difference between photographic and RADAR systems is due to different RADAR system parameters.

2.2 Basic RADAR Principles

RADAR backscatter values are dependent on two groups of parameters. The first of these are the system parameters where a choice can be selected for the wavelength/frequency, polarization and the look angle/incidence angle before conducting

a study. Useful microwave wavelengths are referenced with alphabetic identifiers (Lillesand and Kiefer 1994) according to the following:

k_a	0.75-1.1 cm
k	1.1-1.67 cm
k_u	1.67-2.4 cm
X	2.4-3.75 cm
C	3.75-7.5 cm
S	7.5-15 cm
L	15-30 cm
P	30-100 cm

RADAR imaging systems may include switching mechanisms able to receive the energy in either the same polarization ("like or parallel polarized") or the opposite polarization ("cross polarized") to which it was transmitted, thereby creating four possible combinations identified as HH, VV, HV and VH. The first letter represents the polarization of the transmitted pulse and the second that of the received energy.. The spaceborne RADAR's presently in orbit do not have the capability to switch their polarization for transmission and reception and are, therefore, limited to HH or VV.

RADAR imaging requires an off-nadir illumination of the target area by the transmitted pulse. The degree of the incident angle from nadir may be selected to provide a very steep illumination angle (near nadir) or a very large angle, somewhat similar to a more oblique view, depending on the application of interest. The incident angle effects are significant in areas of high relief as there is uneven illumination across the landscape,

more intense on surfaces at right angles to the illumination, and shadows in the opposite direction.

The second group of parameters relate to target surface roughness and the dielectric constant or the moisture content of the leaves and vegetation. These effects along with wavelength, polarization, resolution, incidence angle, and topography as related to the incident angle of the microwave energy, produce a very complex set of relationships and effects on the RADAR return (Warner 1996).

2.2.1 Sources of Spaceborne RADAR in the Philippines

Spaceborne RADAR s that have been used in previous research include SEASAT, SIR -A, SIR-B, ALMAZ-1, ERS-1, ERS-2 (Lillesand and Kiefer 1994) and the latest RADARSAT, launched on November 4, 1995 (McNally and Pilloud 1995) (Table 2). The new satellites are becoming more effective, as these sensors are more stable than sensors that were launched previously (Toure 1994).

Table 2. Sources of spaceborne RADAR imagery.

	IMAGING SYSTEMS						
PARAMETERS	SEASAT	SIR-A	SIR-B	ERS-1/ ERS-2	JERS-1	ALMAZ	RADAR SAT
LAUNCH DATE	O6/1978	11/1981	08/1984	07/1991	02/1992	03/91	11/1995
BAND - cm	L - 23.5	L - 23	L - 23	C - 5.7	L - 23.5	S 10	C - 5.6
POLARIZATION	HH	HH	HH	VV	HH	HH	HH
LOOK ANGLE	20	47	15.6	23	35	30-60	20-59
RESOLUTION m	25/25	40/40	25/58-17	25/25	18/18	10-30	10-100

Source : (Trevett 1986, and Lillesand and Kiefer 1994).

Research in imaging RADAR began more than half a century ago. The original intent was for military purposes. Thus, the use of spaceborne RADAR for other applications began in 1978 with the launch of the SEASAT (NASA 1986). The research may still be considered in its infancy, since results from various studies are relatively inconsistent. Discrepancies are probably due to the many factors to consider in the approach of using the RADAR image, and the effects of numerous parameters.

2.3 RADAR Imaging of Forests

One very important use of RADAR imaging techniques is in forestry, especially in the tropics. This is because most of the forest areas have high precipitation and humidity and are almost always covered with clouds. Forest surveys may be conducted to estimate the extent of forest resources and monitor their preservation and/or exploitation. These surveys are generally carried out on an extensive scale, or in areas where accessibility is limited (Trevett 1986, Ribbes *et al.* 1997).

A basic knowledge of microwave scattering from forest surfaces is required to understand the capabilities of imaging RADAR to study the forest vegetation. To understand RADAR scattering from complex vegetation cover, it is necessary to think in terms of the different canopy layers affecting the RADAR signature:

1. A canopy with small branches and foliage,
2. A trunk layer which consist of large branches and trunks or boles and
3. The surface layer which may have smaller plants and herbs. The interaction of microwave energy with the vegetative surface may either be a direct scattering

of the microwave energy, or the layers may absorb or attenuate the energy (Moore 1982, Ahern *et al.* 1993).

Forest inventory may be accomplished using the RADAR imagery in the absence of optical images, such as aerial photographs or LANDSAT/SPOT data. It is possible to estimate the tree volume directly from satellite sensor data and also indirectly establish a relationship between crown diameter and stem diameter at breast height as against whole tree volume (Ahern 1993). Hyppa (1997) has even shown that the use of RADAR imagery in stand-wise forest inventory has yielded better results than the use of aerial photography, although further research is required.

Most research has been devoted to the study of the relationship between RADAR backscatter and forest biomass and tree species. In the mixed deciduous Philippines, tree species identification is not as important as biomass or volume relationships. The forest density, which is the thickness of the canopy, combined with the above ground biomass, are the basis for stratification for forest inventory in the Philippines.

2.3.1 Forest Harvesting and Land Clearing

One forest characteristics of importance is the rate at which forest harvesting is occurring and the extent of cleared area. The use of shorter wavelengths such as the C-band RADAR has not been successful for cutover mapping and other harvesting operations (Ahern *et al.* 1993, Banner 1995).

Simulated RADARSAT imagery was also used in the research of Ahern and Banner (1995) in studying forest clearcut mapping in Canada. It was found that the standard mode satellite RADARSAT imagery is unlikely to be used for updating cutover

mapping for provincial forest inventory because of its estimated error of 29% which is lower than what is required. The fine mode beam of the RADARSAT may only be utilized if no optical imagery is available, since an error of 16% resulted from the study.

Because of their longer wavelengths, the JERS-1 and the Almaz satellites are more superior in clear-cut forest determination. However, clearcuts cannot be consistently detected in ERS-1 images particularly in rugged terrain. The JERS-1 images were the best images in separating clearcuts from forest and wetland, followed by ALMAZ which uses a longer wavelength than ERS-1 (Yatabe and Leckie 1995, Ahern and Raney 1993). These environmental influences on clearcut backscatter and the temporal dynamics of the backscatter of new cuts warrants further research (Yatabe and Leckie 1995).

According to Banner and Ahern (1995), users of RADAR imagery interested in clearcut mapping should acquire imagery with large incidence angles of 60 degrees or greater. In contrast, Brown *et al.* (1996) states that smaller incidence angles and high resolutions are required to successfully monitor clear-cuts, forest regeneration, and infrastructure developments because the location and size of the feature of intent maybe accurately identified.

There is little consensus to date, therefore, on the optimum set of system parameters to ensure clearcut and land clearing mapping success.

2.3.2 Forest Biomass

Forest biomass is defined as the quantity constituted by living organisms in the forest ecosystem in terms of mass (Alemdag 1980). For this research, biomass will be confined only to the mass that is above ground which include trees and shrubs. The

assumption of three dimensional RADAR backscatter model will be used in this study, since it is a good prediction of total backscattering averaged over the site particularly in a coniferous forest (Sun and Simonett 1995).

The results from the study of Sun and Simonett (1995) show that the correlation between the backscattering coefficient and forest stem volume (biomass) varies from positive to negative and is dependent on canopy and moisture. However, multi-temporal ERS-1 RADAR images can be successfully used for estimating the forest stem volume (Pulliainen *et al.* 1996). Forest type mapping and biomass estimation, however, are still difficult to determine, especially with C-Band RADAR (5.6 cm wavelength) such as employed by RADARSAT. The longer wavelengths of P-band (75-133cm wavelength) and L-band (15-30cm wavelength) are recommended for this kind of project (Brown *et al.* 1996, Yatabe and Leckie 1995). The use of the C-band RADAR, though is applicable to use for forest type mapping especially in the coniferous forest structure (Wilson 1996).

Backscatter increases from zero at the earliest stages of regeneration but levels off and becomes saturated at relatively low biomass amounts (Ahern *et al.* 1993). If the universal SAR biomass equation for earth's forest is not feasible, the user of RADAR data should stratify forest stands along structural variation as a source of error (Imhoff 1995).

The C-band is useful only in low forest type mapping and biomass estimation in coniferous forest stands. (Dobson *et al.* 1992, Li 1996). Backscatter from hardwoods is greater than in softwoods and in mature boreal forest, the species composition is most important in affecting C- and X-band backscatter and consequently, these bands are suitable only for forest species differentiation (Ahern *et al.* 1996)

The investigations by Sader (1987) and Wu (1990) indicate that L-band multipolarization SAR data are poorly correlated with forest biomass and stand structure variables in uneven aged broad-leaved forests which are typical of the tropical region (Sader 1990). However the investigations conducted by Dobson *et al.* (1992) and Li (1996) show that the longer wavelengths such as P- and L-bands are more suitable for these applications, especially biomass estimation.

The long wavelengths of RADAR have a unique potential for mapping aboveground biomass levels and to identify regions of deforestation and regrowth rates. These long wavelengths with HH polarization as used in tropical forests is correlated with stem biomass which is a more direct indicator of total biomass especially in areas of high biomass levels (Rignot 1995). As RADAR frequency increases, the overall sensitivity to variations in biomass decreases. The L band at HH polarization is more sensitive to variations in bole biomass than VV polarization in the pine forest stands where the above ground biomass up to 35-40 Kg/m2. Biomass estimation is going to be dependent on wavelength and frequency (Kasischke *et al.* 1995).

Research shows that the longer wavelength of the L-band is particularly sensitive to the backscatter of branches with 0.2 cm to 2 cm radius which represent an important fraction of branch biomass. The L-band is also moderately influenced by soil condition. The HV polarization is most sensitive to woody biomass, while HH and VV polarizations contain different information useful for classification (Ferrazoli *et al.* 1995). Classification accuracy using RADAR imagery is up to 90% which is comparable if not superior with optical sensors independent of cloud cover. Although the C-band is more useful for classification than either L- or P- bands using HV (Rignot *et al.* 1994), cross

polarized data from longer wavelengths were the best RADAR channels for mapping total above ground forest biomass.

2.3.3 Local Topography and Incident Angle Effects

Warner *et al.* (1996) has studied the effects of local incidence angle using the X and C-band RADAR in boreal forest communities. They found that RADAR backscatter is controlled predominantly by local incidence angle effects, which can be approximated by a linear function of the cosine of the incidence angle. Forest composition has much smaller effect on RADAR backscatter than local incidence angle effects. These results conflict with those of Ahern *et al.* (1996) which states that species composition is the most important factor affecting C-and X-band backscatter in boreal forest. This should be considered when conducting forest classification using RADAR. forest dominated conifers. The X and C band RADAR data with small incidence angle provide optimum identification of forest composition (Warner *et al* 1996).

2.3.4 Seasonal Effects

The seasonal change may be an important factor to consider in the measurement of RADAR backscatter. With respect to the study of forest cover type mapping in coniferous stands, the March image gave the greatest separability of forests from clearcuts compared to images from September and November (Drieman 1994). Also, a multi-season color composite is superior to single date imagery for forest type discrimination. Multi-season composite images facilitate ready identification of forest types because separability is greatly increased. RADARSAT may be an effective alternative for

inventory and updating purposes. This is however, applicable only in temperate regions (Drieman 1994). Nonetheless, a multi-season image may prove useful in regions of tropical forest where distinct wet and dry season exist. The presence of high dielectric constant in moist canopy will give different backscatter properties compared to those of the dry state during the dry season.

2.4 Summary

The sensor parameters of the JERS-1 satellite make it ideal for investigating the relationship between forest density and backscattering properties in the tropics. The HH polarization and the long wavelength of L-band are optimal for biomass determination and canopy penetration respectively. Also, the small incidence angle of 35 degrees and high resolution of 12.5 meters are best for species identification.

CHAPTER 3. MATERIALS AND METHODS

3.1 Introduction

The study proceeded through a series of logical steps from the acquisition of published analogue maps and digital RADAR data, through the conversion of the maps to digital form to register with the RADAR data, to the sampling and statistical analyses of the RADAR digital data for various classes of vegetation and slopes. The details are included in the following discussion.

3.2 Data Acquisition

3.2.1 Topographic Map

A topographic map is a cartographic representation of the earth's surface which includes much data, for example, planimetric information showing the roads, rivers, bridges, etc. One important information item is elevation which is represented in the form of contour lines. Topographic maps for this study were acquired from the National Mapping and Resource Information Authority (NAMRIA) of the Department of Environment and Natural Resources (DENR), at a scale of 1:50,000. The contour interval of 20 meters is supplemented with 5 meters and 10 meters contours in areas with relatively flat surfaces. In these areas, the contour interval of 20 meters is spread out and the elevation in between the contours is difficult to pinpoint (Figure 3). Four topographic sheets were required to cover the entire study area: 7274-1 (Maria Aurora), 7374-4 (San Luis), 7274-2(Ligaya), and 7374-3 (Dingalan). The projection used is a Transverse Mercator using the Clarke's 1866 spheroid, with the Luzon datum for the horizontal

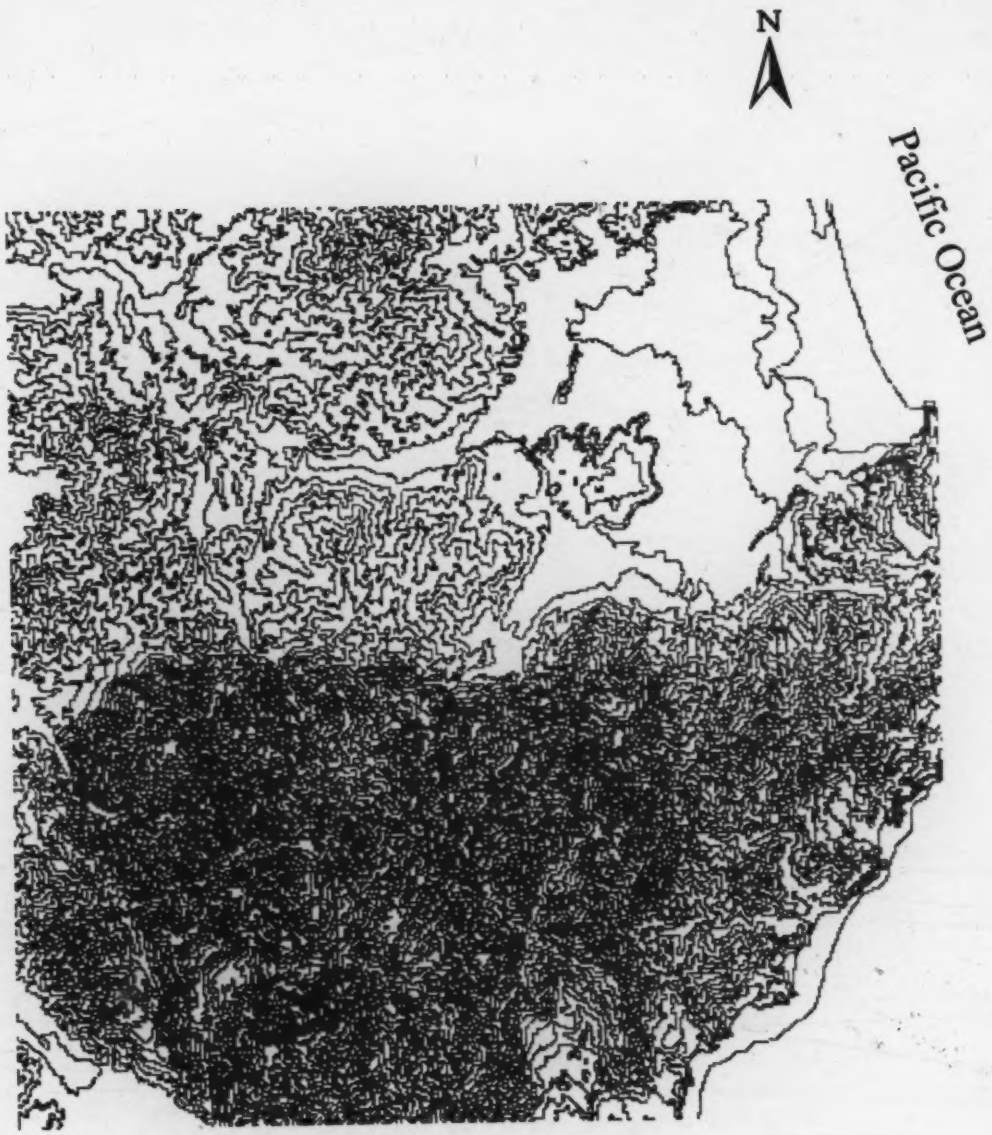


Figure 3. Vector file of the contour lines digitized from the 1:50,000 topographic map of the study area. The contour interval in the steep slopes is 100 meters. The map dimension is 38 x 36 kilometers.

control. The maps were produced by the U.S. Coast and Geodetic Survey, 29th Engineer Battalion and the Philippine Coast and Geodetic Survey.

3.2.2 Vegetation Cover Map

The Vegetation Cover Map (Figure 4) was produced in July 1991 from a joint project report prepared by the National Mapping and Resource Information Authority (NAMRIA) and the Aurora Integrated Area Development Project (AIADP) (NAMRIA 1991). The aim of this joint project, funded by the European Economic Community through the AIADP and implemented by NAMRIA, was to undertake the mapping and inventory of forest resources for the province of Aurora. There were various thematic maps generated from the project including a regulatory map, a land classification map, the vegetation map used for this study and others. The scale of the map is 1:50,000 which follows the geographic coordinates from the topographic map. The data used for delineation of the vegetation was obtained from the interpretation of aerial photographs obtained in 1989 at a scale of 1:25,000 and supplemented by SPOT satellite imagery, taken in 1988 for areas not covered in 1989 (NAMRIA 1991).

3.2.3 LANDSAT Thematic Mapper Image

A LANDSAT Thematic Mapper image (Path 116, Row 49) acquired on April 2, 1993, under a NAMRIA project with the Japan International Cooperation Agency, was used to confirm and verify the land use and vegetative cover of the study area. A 30 x 40 kilometer subscene was extracted for the study area and provided by NAMRIA.

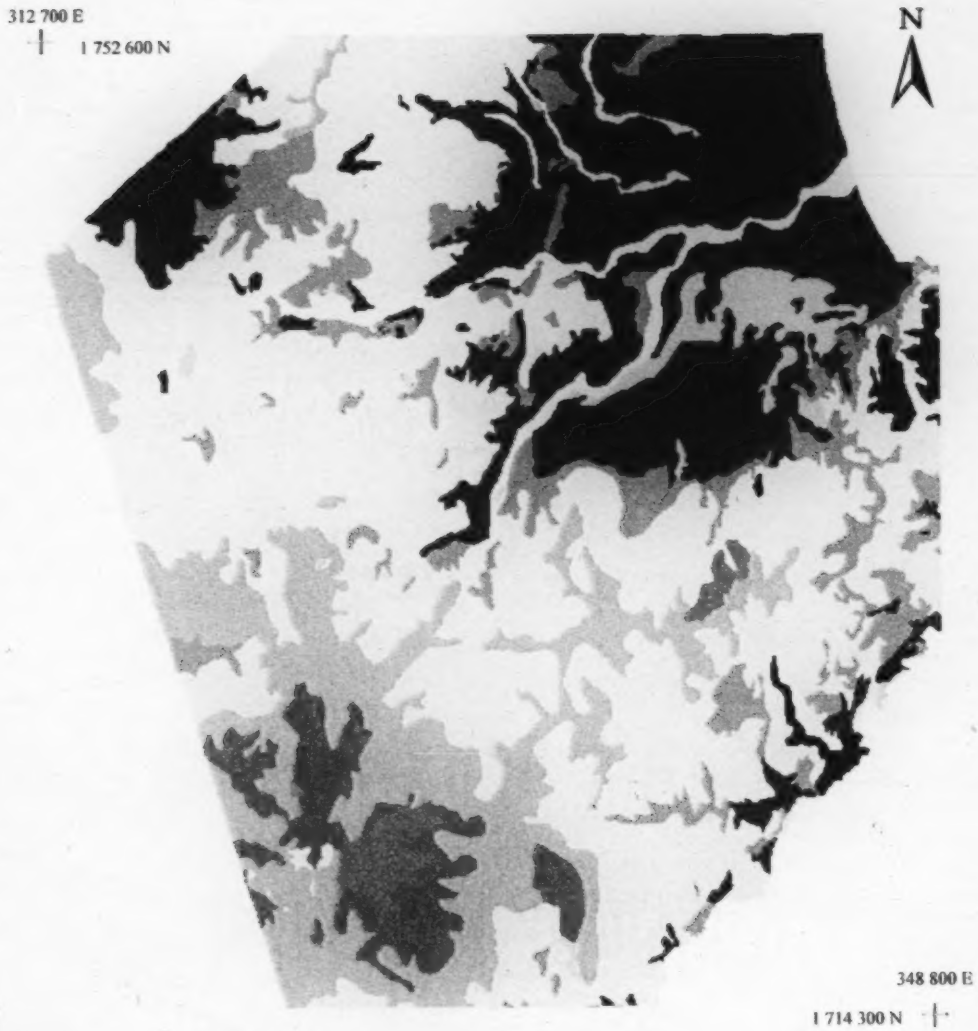


Figure 4. Vegetative cover map of the study area.

3.2.4 JERS-1 Data

A Japanese Earth Resources Satellite-1, or JERS-1, SAR image obtained for the study area on December 15, 1996, was acquired from RADARSAT International in Vancouver, British Columbia. It was delivered on CD-ROM in a CEOS-BSQ (Committee on Earth Observation System - Band Sequential) format with an image center at N15^0 58' / E121^0.26'. It is in image path (K)/column number 89-row (J)/Line number 274 with a shift of 4/10th of an image to the south of the nominal centre point, to ensure coverage of the study area.

The JERS-1 is a joint undertaking of the NASDA (National Space Development Agency) and MITI (Ministry of International Trade and Industry), both of the Japanese government. The mission is focused on earth resources such as geology, agriculture, forestry, land use, ice monitoring and coastal monitoring (NASDA 1992). The satellite was launched on February 11, 1992 from the Tanegashima Space Center in Kagoshima Japan. It had a design life of only two years, but it has exceeded that estimate and is still serviceable as of this writing. Its altitude is approximately 580 kilometers with an inclination of 98 degrees from the equator. The RADAR swath width is 75 kilometers and it orbits around the earth in approximately 96 minutes, with a 44 day repeat cycle (NASDA 1992, ASF 1993).

3.3 Digital conversion of analogue maps

Digitization is a process of converting the analogue data (e.g. contour lines) to a digital format (binary code) which can be read and understood by the computer. For a map to be converted to digital codes in binary format, a digitizer may be used to capture

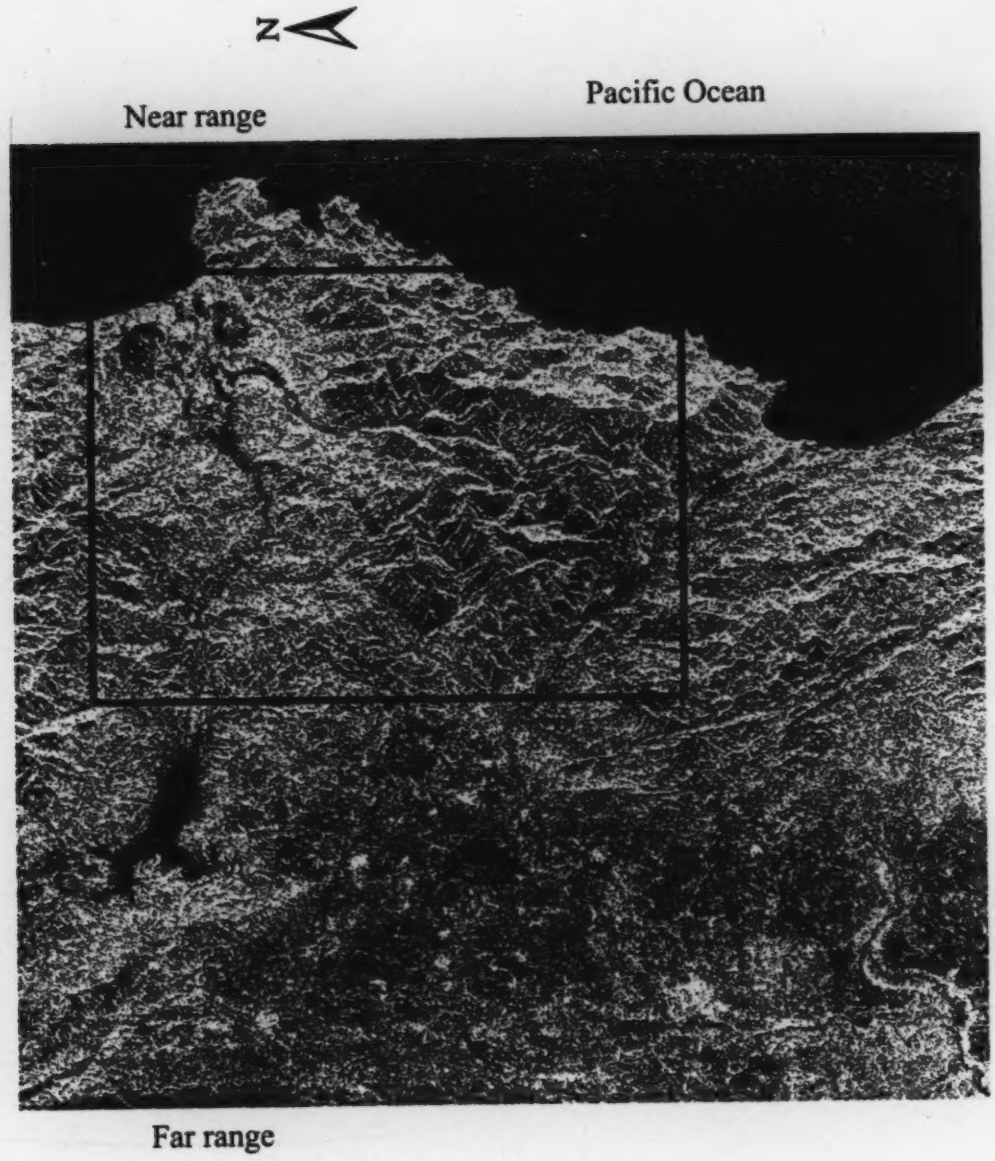


Figure 5. Whole scene JERS-1 image (Path 89 / Row 274) taken on December 15, 1996. Pixel interval is 12.5 meters and ground distance is 75 x 75 kilometers. Study area is outlined.

the line data from the map and save it subsequently in the computer disk, as described in the following.

3.3.1 Digital conversion of the topographic map

The study site has a rugged, mountainous terrain with an elevation from sea level to 1885 meters in less than 10 kilometers linear distance. This abrupt change in elevation would be difficult to digitize using the 20 meter contour interval on the map, since many locations with steep slopes would show many very fine lines with an approximate 0.2 millimeter distance between them. This distance was estimated from the presence of five lines per 100 meter contour interval in a one millimeter distance. It would be very difficult to trace these lines using the cursor of the digitizing table without error. To solve this problem, only the lines for every 100 meters were hand drawn onto a mylar sheet covering the four adjacent topographic map sheets, to create one contiguous map for the study area. As the contour lines were traced for the study area, care was taken to ensure that there were no cross lines that could add confusion, or be improperly labeled. This included all the geographic coordinates that would be required in the digitization process. The Geographical Resources Analysis Support System (GRASS version 4.1) software's digitization program 'v.digit' was used to select the geographic coordinates as the input values. The input data were in vector file, and were later converted to raster with 25 meter pixels, using "v.to.rast", in preparation for the generation of a digital elevation model (DEM). A dimension of 25 meter was chosen for the DEM pixel size so as to register with the resampled 25 meter pixels of the TM satellite data (Section 3.2.3). The vector

file of the same contour lines was also converted to a raster with 12.5 m pixels for the generation of a DEM that would register with the JERS-1 data (Section 3.2.4).

3.3.2 Digital conversion of the vegetation map

The vegetative cover map was digitized in the same manner as the topographic map, using UTM coordinates. There are 25 different vegetation classes identified in the map of which only six were forest classes, namely mossy forest, old growth dipterocarp forest low altitude , old growth dipterocarp forest high altitude, residual dipterocarp forest, sub marginal forest, and brushland, with two non-forest classes namely, grassland, and open area (Section 1.3.4). All the other classes are included within the extensive and intensive land uses in the agriculture areas.

3.4 Generation of the Digital Elevation Model

A digital elevation model is very useful for aiding in satellite image interpretation because it gives an idea of the three dimensional characteristics of the land surface. However, DEM's are particularly beneficial in the analysis of RADAR images (Figure 5), since the effects of topographic change are severe, especially in mountainous areas in which "layover" and shadows occur (Guindon 1995). The "layover" effect is evident within the JERS-1 image of the study area (Figure 5) and is the result of the RADAR's transmitted pulse illuminating the tops of near vertical features (mountains) before the sides or bottoms. The return signals from the top of the features arrive back at the antenna before those from the sides or bottoms. Thus the tops are placed in the image closer to the

near range than the bottoms producing the visual "layover" effect (Lillesand and Kiefer 1994).

A digital elevation model DEM was prepared not only as an aid in the interpretation of the RADAR data, but also for the interpretation of the LANDSAT TM data, and for the correction of the vegetation map information including field site identification and verification. The DEM will also provide slope and aspect for the area characterization for future use in the analysis of the topography (Kellndorfer *et al.* 1996). The primary use, for this study however, is for the geometric correction of the RADAR data (Section 3.6)

The raster file of the contour lines (Section 3.3.1) was used for the GRASS surfacing program "r.surf.contour" to generate the 25 m DEM using a default "flood fill" algorithm (GRASS 4.1 1993). This provided a DEM compatible with the LANDSAT TM image. This process of generating a 25m DEM for the study area was exceedingly time consuming (11days). The process for a 12.5 m DEM would be even slower. Therefore, the vector file of the contour lines was exported to the Arc-Info GIS software and used to generate the 12.5m DEM compatible with the JERS-1 data, using the iterative finite difference interpolation technique (Arc Command Reference 7.0 1991). This required less than one day of processing time.

3.5 Slope magnitude and aspect classes

The 12.5 m DEM was exported back to GRASS. The slope magnitude and aspect classes were calculated, as integer values,simultaneously using the "r.slope.aspect" program in GRASS. Slope magnitude values were reported between 0 and 90 degrees

inclination, whereas aspect is recorded as an angle between 0 and 360 degrees, with zero towards the east which may be later reclassified to define zero towards the north.

3.5.1 Slope classes

The individual slope magnitude values were reclassified into six different classes to include a class to encompass the magnitude with the strongest assumed RADAR return. Reclassification was based on the assumption that the slopes perpendicular to the transmitted pulse of 35 degrees incident angle would have the greatest backscatter, all other terrain characteristics being equal (Guindon 1995). Classes were created with a ten degree slope range as in Table 3. Class 4 includes the 35 degree incident angle of JERS-1 data.

Table 3. Slope magnitude classification.

Slope Class	Degrees of Slope
Class 1	0 - 9
Class 2	10 - 19
Class 3	20 - 29
Class 4	30 - 39
Class 5	40 - 49
Class 6	>49

3.5.2 Aspect classes

The JERS-1 satellite imaged the study area from an azimuth of 98 degrees east from north. Based on the assumption that backscatter would be greatest from terrain facing the satellite, and that the shadow effects would increase as the slope and aspect

changed to 180 degrees away from the satellite (Guindon 1995), the 360 degrees of aspect was subdivided into 45 degree increments to create eight classes (Table 4). Initially, the midpoint at 98 degrees, the aspect directly facing the antenna, was used as a starting point and classification proceeded clockwise. Perfectly flat areas have no aspect and are assigned a zero value. These are dominantly agricultural areas in Aurora Province, outside of forest reserves, and were not sampled nor included in the analyses.

Table 4. Aspect classification.

Aspect Class	Angle in Degrees
Class 1	76- 120
Class 2	121-165
Class 3	166-210
Class 4	211-255
Class 5	256-300
Class 6	310-345
Class 7	346-360 & 1-30
Class 8	31-75

These two groups of classes were combined to create 48 classes of slope and aspect. These were identified using a 2 digit code in which the first digit references the slope class by number and the second the aspect class by number (Appendix 4).

3.6 Geometric correction of the JERS-1 image

The process of image registration for a RADAR image to the coordinates of a planimetric map is not the same as the process of image registration for a LANDSAT or

SPOT image. Guindon *et al.* (1982), Bayer *et al.*(1991), and Guindon (1995) have all found that incorporation of digital elevation models is necessary for RADAR image correction, especially in mountainous terrain. Digital elevation data allows for the imagery to be corrected from its two dimensional image projection. The GCP Works package in the PCI image processing software was used to geometrically correct the JERS-1 data. There were four steps necessary in undertaking the geometric correction of the RADAR image:

1. A DEM of 12.5 meter resolution is required and must be created if none exists.
2. From the DEM, a simulated RADAR image will be generated using the algorithm of Guindon and Adair (1992) and the provided orbital parameter as input.
3. Ground control point collection should be well distributed throughout the study area and on different elevations as well. In this case, 18 ground control points were collected in the study area, with an accuracy of one half pixel in both the x and y directions (0.56 and 0.53 respectively). A complete listing of the ground control points is included in the Appendix 1.
4. The image registration was performed using the SARGEO program. The program was used specific to the RADAR data where the RADAR image was tied to the DEM at the Ground Control Points selected based on the simulated data created by SARSIM1.

3.7 Verification of the Vegetative cover map

The vegetative cover map being used for the study was published in 1991 (NAMRIA 1991). Since the RADAR data was acquired in late 1996, there is a need to verify the map information. Verification was provided by a visual analysis of the 1993 LANDSAT Thematic Mapper image and was further supplemented by fieldwork. The LANDSAT Thematic Mapper image was geometrically corrected using the ground control points taken from the topographic map and identified on the image, using a fourth order polynomial and resampled to 25m pixels using bilinear interpolation (PCI 1996). The image was then registered to and draped over the 25 meter resolution DEM to aid in the visual identification of major land use changes such as land clearing.

Fieldwork was carried out with the assistance of NAMRIA technical personnel between June 1 and July 15, 1997. The purpose was to verify the vegetative cover and the forest densities present within the study area. Verification was accomplished by visiting areas of vegetation change that were easily visible on the LANDSAT Thematic Mapper image and updating the vegetative map accordingly.

3.8 Sampling and Statistical Procedures

A stratified random sampling design was employed for the JERS-1 data. with a maximum number of 40 samples per stratum. The strata were defined as combinations of individual forest densities (from the 8 cover classes) individual slope magnitude classes (from the 6 slope classes), and individual slope aspect classes (from the 8 aspect classes). This lead to a possible 384 separate combinations.

The area of the combinations of forest density + slope magnitude + slope aspect were superimposed onto the JERS-1 image. JERS-1 gray level values were recorded for pixels selected at random from within the area of each combination. These data were encoded manually using Excel version 7.0 spreadsheet (Microsoft Office 1995) and used to test for significant differences in JERS-1 gray level values among areas of different density, aspect, and slope magnitude.

The data analysis was done using the statistical package Statistical Analysis System (SAS) version 6.1 (SAS manual). Although the statistical design is a two way Analysis of Variance (ANOVA), a general linear model was used to process the data. A simple two way ANOVA could not be used, since the sample sizes were not equal. A Duncan's multiple comparison test was employed to test the pairwise comparison of the different forest densities and interactions between their various slopes and aspects based on RADAR backscatter values. The test of significance was astablished at 95% probability. Since the data were initially skewed, a logarithmic transformation was implemented to obtain normal distribution.

Chapter 4. RESULTS AND DISCUSSION

This chapter is devoted to the results of the analyses and the discussion of these results, in the general order in which they are performed.

4.1 The Analysis of the Digital Elevation Model and the Vegetation Map

The Digital Elevation Model was generated using the contour data presented in Figure 3. The final model was presented in two formats: a) with continuous color tone to illustrate the spatial distribution of elevation values (Figure 6), and b) as a perspective view mesh to illustrate the appearance of the landscape in the study area (Figure 7).

The proportions of the study area in each of the slope magnitude and aspect classes are given in Tables 5 and 6 respectively. The proportion of the study area in each slope magnitude class decreases as the slopes increase (Table 5). The slope aspect classes are generally well distributed within the study area although a slightly greater proportion of the area is characterized by east and southeast aspects (Classes 1, 2, 3, & 8) (Table 6).

The proportions of the different vegetation classes within the study area are not equal. The direct interpretation of the land use was not accomplished from the LANDSAT TM image as there are many shadows and cloud covered areas (Figure 8). The image data were used to update the existing vegetation map (Figure 4).

The tabulation of the data from the final digitized vegetation cover map indicates that the "residual" forest is dominant while "Old Growth Forest at High Altitude" and the "Submarginal Forest" occupy minor proportions of the study area (Table 7). The "Other" class in Table 7 includes areas of agriculture, built-up areas, and water, concentrated in the northeast portion of the study area.

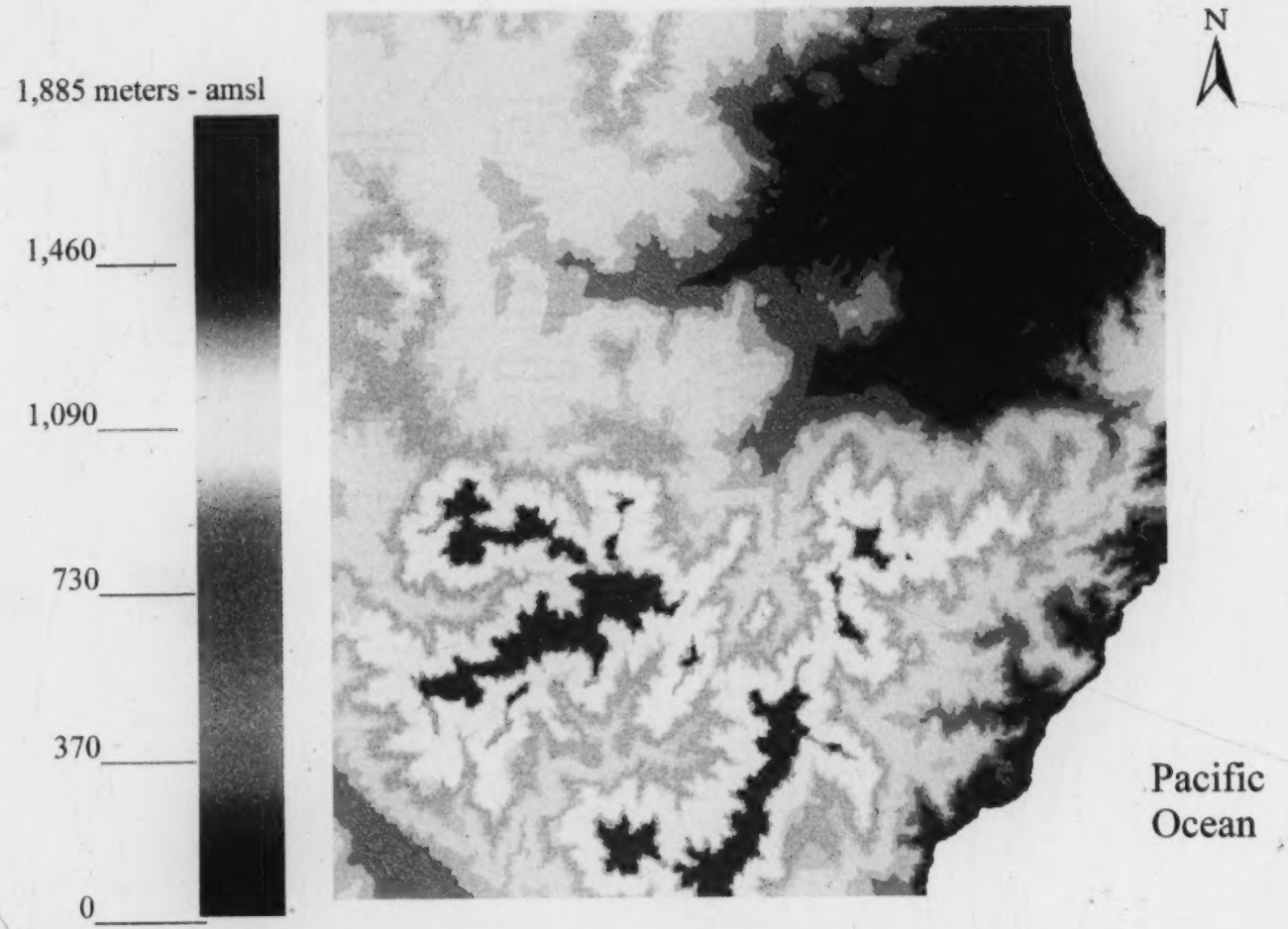


Figure 6. The study area in continuous color tone from blue to dark red, representing elevations from 0 to 1,885 meters above mean sea level, from the digital elevation model.

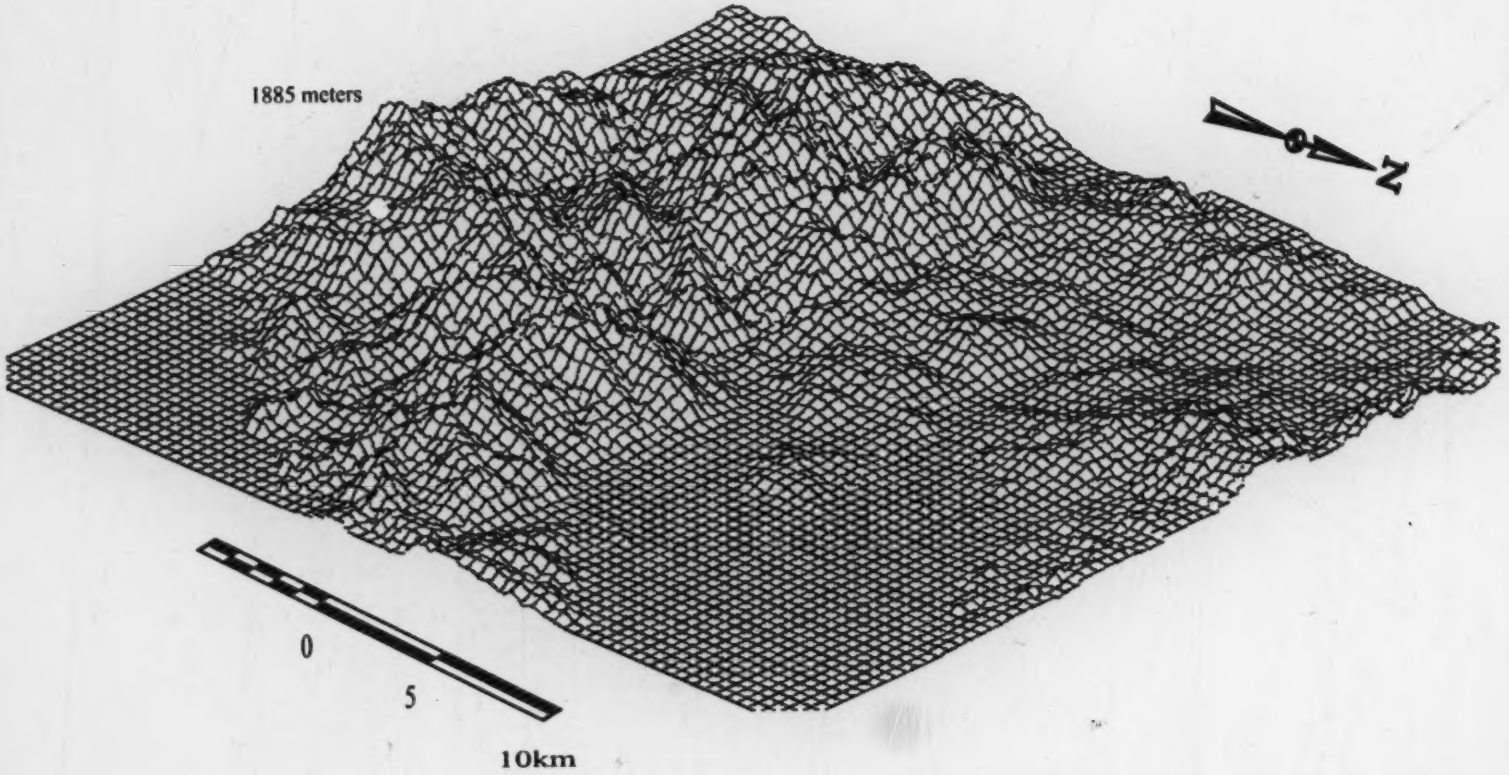


Figure 7. The digital elevation model of the study area portrayed as a three dimensional mesh with a perspective view. Mesh lines are 200 meters apart in this presentation.

Table 5. Distribution of slope magnitude classes within the study area.

Slope Magnitude Classes	Areas in Hectares	% of Study Area
1	39,387.8	41.0
2	19,517.6	20.3
3	14,283.5	14.9
4	12,445.1	13.0
5	7.993.5	8.3
6	2,408.2	2.5
Total	96035.7	100

Table 6. Distribution of slope aspect classes within the study area.

Slope Aspect Classes	Areas in Hectares	% of Study Area
0	12,531.1	13.0
1	13,237.3	13.8
2	11,586.0	12.1
3	10,636.6	11.1
4	9,884.9	10.3
5	8,593.3	8.9
6	8,323.8	8.7
7	9,134.8	9.5
8	12,107.9	12.6
Total	96,035.7	100.0

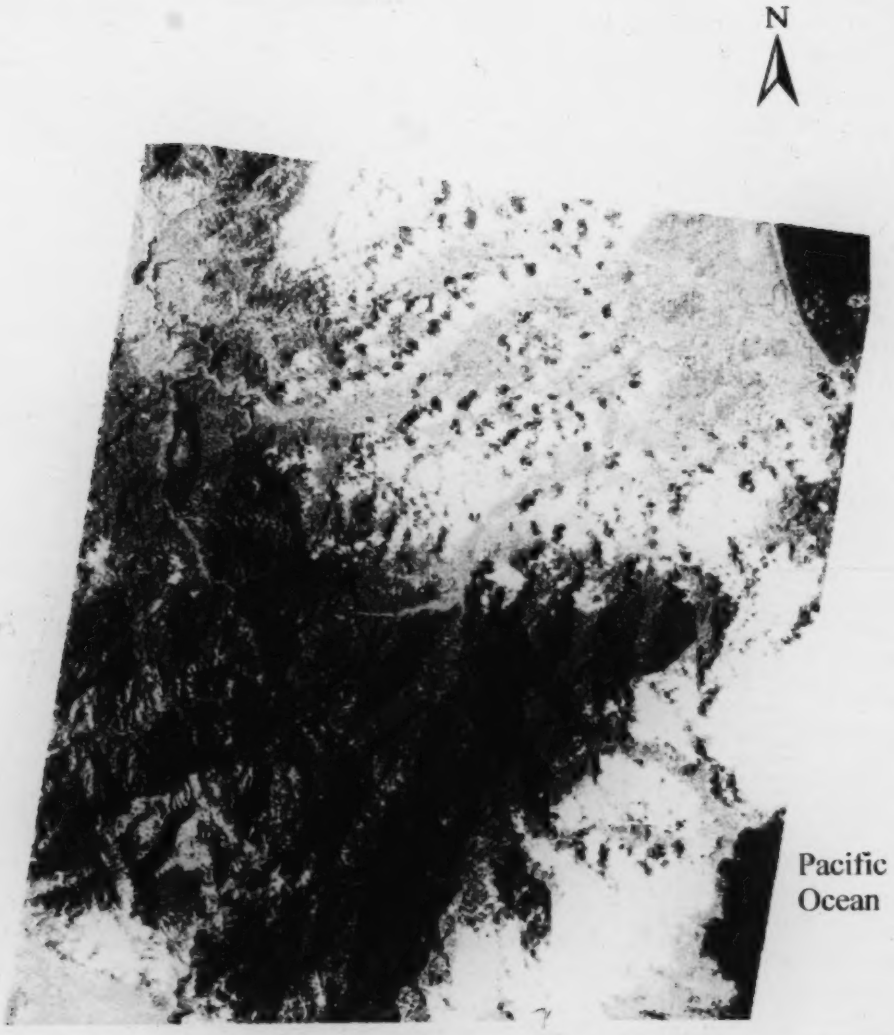


Figure 8. Subscene of LANDSAT Thematic Mapper image (Path 116 / Row 49) taken on April 2, 1993 of the study area. Color composite bands 2, 3, 4 as BGR respectively. The image is geometrically corrected and resampled to 25 x 25 meters to match UTM values.

Table 7. Proportions of the study area occupied by each of the forest density classes.

Density Class Number	Forest Density Class	Area in Hectares	% of Study Area
1	Mossy forest	14,446.4	15.0
2	Old Growth Low Alt	4,008.6	4.2
3	Old Growth High Alt	1,162.3	1.2
4	Residual forest	41,812.2	43.5
5	Brushland	8,410.5	8.8
6	Submarginal forest	1,302.2	1.4
7	Grassland	1,910.6	2.0
8	Open land	2,606.8	2.7
-	Other	20,376.1	21.2
	Total	96,035.7	100.0

Combinations of slope magnitude and aspect classes with the various land cover classes reveal a relatively low proportion of the total study area within each possible combination, usually less than 1% of the total (Table 8). Of particular interest is the reduction in submarginal forest, grassland, and open land (vegetation density classes 6, 7, and 8) within areas of slope magnitude classes 5 and 6. The "Residual Forest" (class 4) occupied the greatest proportion of the study area and is found on all slope magnitude + slope aspect combinations (Table 8).

4.2 The Corrected JERS-1 Image

The simulated RADAR image, based on the relationship between slope magnitude and aspect as determined from the DEM and the altitude, azimuth, and incident angle of the satellite RADAR system, provides assumed gray level values for the study area (Figure 9). It was used with the uncorrected JERS-1 image (Figure 10) to locate ground control points. In the corrected image (Figure 11) the degree of "layover" in the uncorrected image results in a geometric stretching of the high gray level values for more area than the very tops of the mountains. This is accompanied by a geometric compression of the shadowed areas. This alteration to gray level values may cause errors in the data collected for specific land cover classes in these areas. This is also illustrated by draping the corrected JERS-1 image over the DEM (Figure12).

Table 8. Generalized proportions of the forest density classes in the study area for each slope magnitude + slope aspect class combination. Forest density classes occupying less than 0.01 % of the study area (approximately 650 pixels) are excluded.

Forest Density Class Numbers from Table 7:

1. Mossy Forest
2. Old Growth Forest Low Altitude
3. Old Growth Forest High Altitude
4. Residual Forest
5. Brushland
6. Submarginal Forest
7. Grassland
8. Open Land

Slope Magnitude Class	Slope Aspect Class	% of Study Area	Generalized proportions of the study area			
			1.8-1.0%	0.9-0.5%	0.4-0.1%	0.09-0.01
1	1	4.5	4		1, 5, 7, 8	2, 3, 6
1	2	4.3	4		1, 5, 7, 8	2, 3, 6
1	3	3.6	4		1, 5, 8	2, 3, 6, 7
1	4	3.2	4		1, 5, 8	2, 3, 6, 7
1	5	2.6	4		1, 5	2, 3, 6, 7, 8
1	6	2.8	4		1, 5	2, 3, 6, 7, 8
1	7	3.0	4		1, 5, 8	2, 3, 6, 7
1	8	3.8	4		1, 5, 8	2, 3, 6, 7
2	1	3.1	4		1, 5	2, 3, 6, 7, 8
2	2	2.7	4		1, 5	2, 3, 6, 8
2	3	2.8	4		1, 5	2, 3, 6, 7, 8
2	4	2.2	4		1, 2, 5	3, 6, 8
2	5	2.1	4		1, 2, 5	3, 6, 7, 8
2	6	2.0	4		1, 2, 5	3, 6, 8
2	7	2.4	4		1, 5	2, 3, 6, 7, 8
2	8	2.9	4		1, 5	2, 3, 6, 7, 8
3	1	2.3	4		1, 2, 5	3, 6, 8
3	2	2.0	4		1, 2, 5	3, 6, 8
3	3	1.9	4		1, 5	2, 3, 6, 8
3	4	1.8			1, 2, 5	3, 6
3	5	1.6		4	1, 2, 5	3, 6
3	6	1.4		4	1, 2	2, 5, 6
3	7	1.6		4	1, 5	2, 3, 6, 7
3	8	2.3	4	1	5	2, 3, 6, 7

Table 8. Generalized proportions of the forest density classes in the study area for each slope magnitude + slope aspect class combination (Continued).

Forest Density Class Numbers from Table 7:

1. Mossy Forest
2. Old Growth Forest Low Altitude
3. Old Growth Forest High Altitude
4. Residual Forest
5. Brushland
6. Submarginal Forest
7. Grassland
8. Open Land

Slope Magnitude Class	Slope Aspect Class	% of Study Area	Generalized proportions of the study area			
			1.8-1.0%	0.9-0.5%	0.4-0.1%	0.09-0.01
4	1	2.1	4	1	2, 5	3, 6
4	2	1.6	4		1, 5	2, 3, 6, 8
4	3	1.5		4	1, 2, 5	3, 6
4	4	1.6		4	1, 2, 5	3, 6
4	5	1.4		4	1, 2	3, 5, 6
4	6	1.3		1, 4	2	3, 5, 6
4	7	1.4		1, 4		2, 3, 5, 6
4	8	2.0	4	1	2, 5	3, 6
5	1	1.4		4	1, 2	3, 5
5	2	1.0		4	1	2, 3, 5, 6
5	3	0.9		4	1, 2	3, 5
5	4	1.0		4	1, 2	3, 5
5	5	0.9			1, 2, 4	3, 5
5	6	0.9			1, 2, 4	3, 5
5	7	0.9			1, 4	2, 3, 5, 6
5	8	1.2		1, 4		2, 3, 5, 6
6	1	0.4			1, 4	2, 5
6	2	0.3			4	1, 2, 3, 5
6	3	0.3			4	1, 2, 5
6	4	0.3			1, 4	2, 3, 5
6	5	0.3			1, 4	2
6	6	0.2			1	2, 4
6	7	0.2			1	2, 4
6	8	0.3			1, 4	2, 5, 6

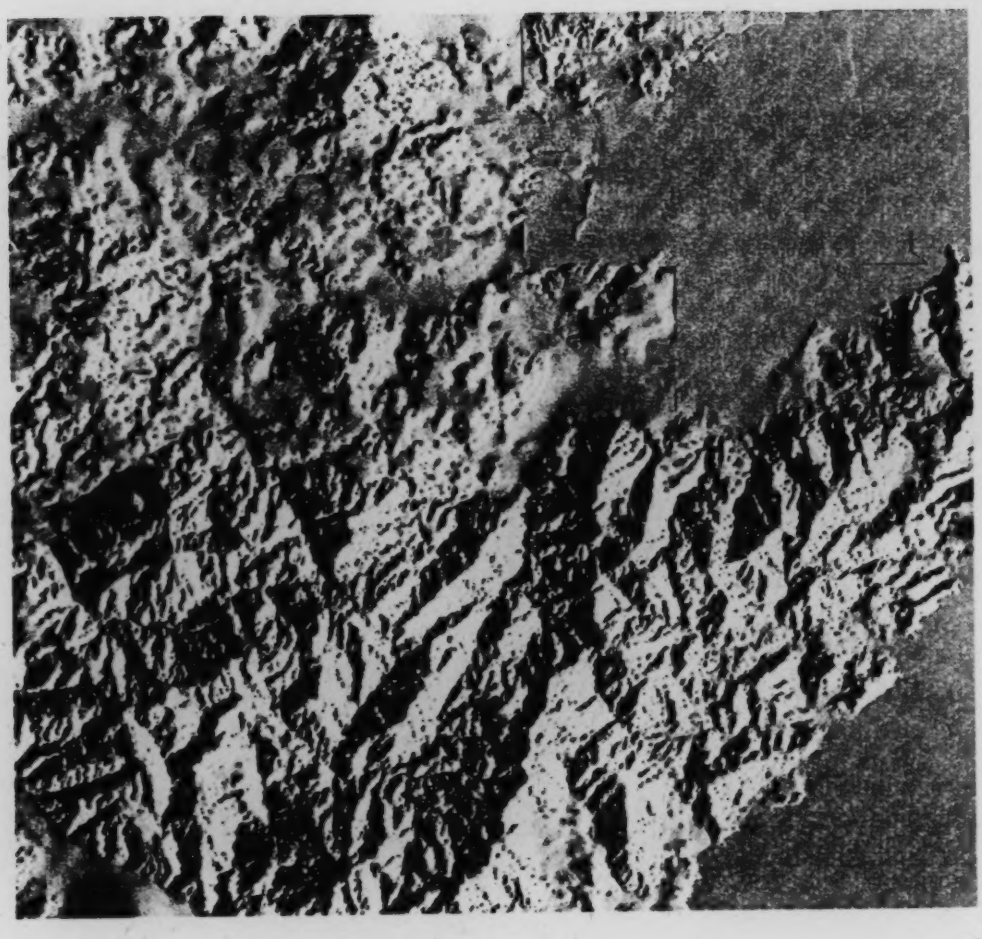


Figure 9. Simulated RADAR image of the study area based on orbital parameters of JERS-1.

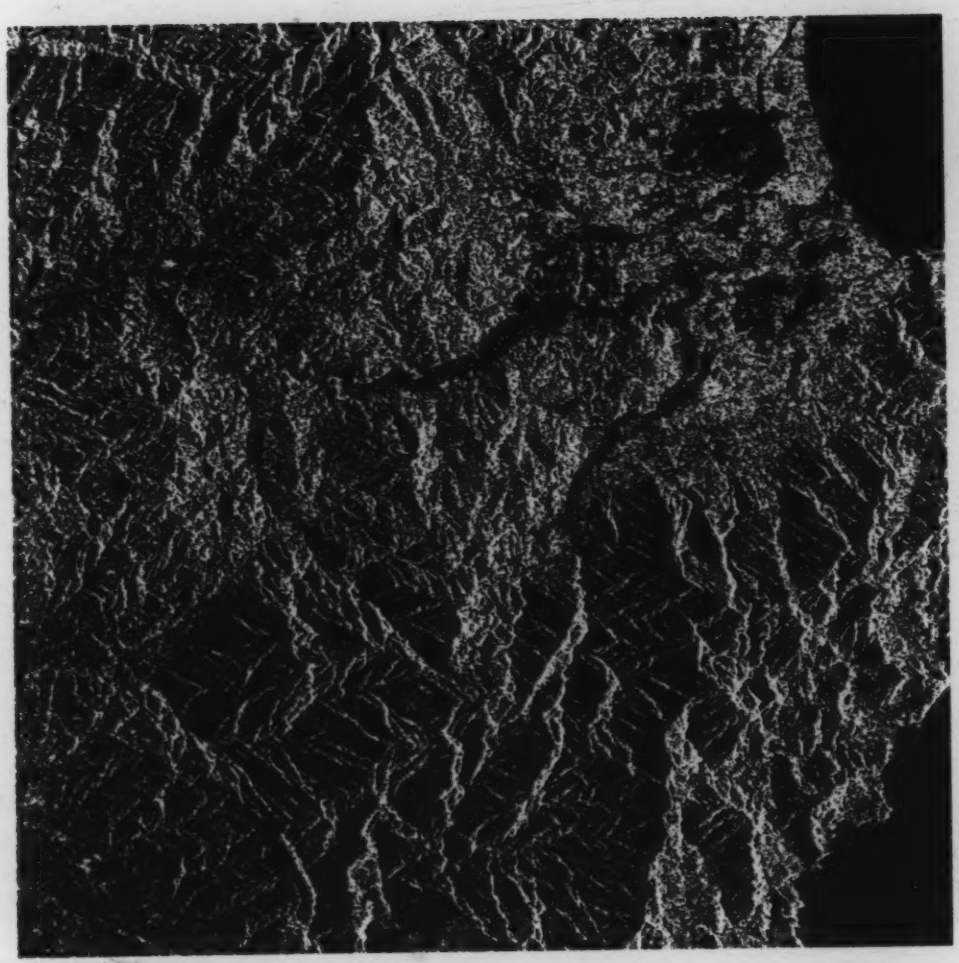


Figure 10. Subscene of the JERS-1 uncorrected image of the study area with 90 degree rotation. The ground distance is 38 x 36 km.

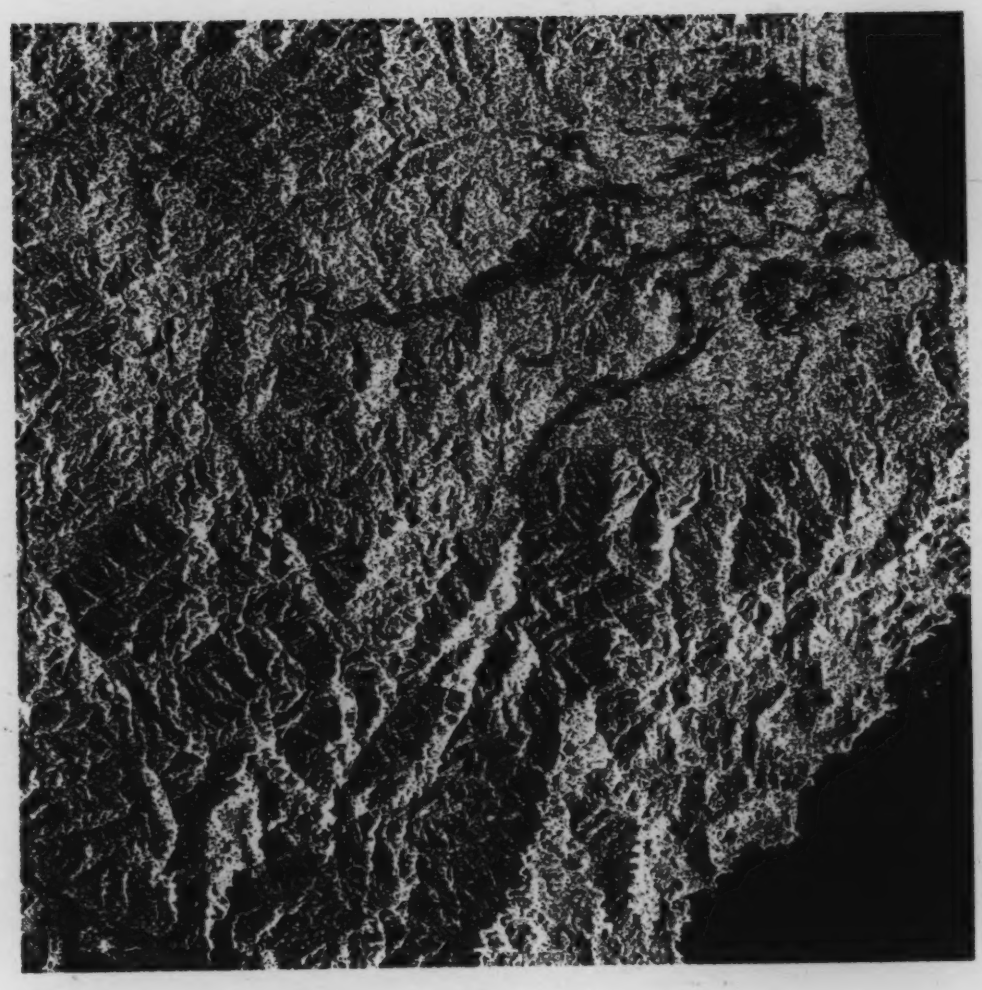


Figure 11. Geometrically corrected JERS-1 image of the study area. The ground distance is 38 x 36 km.

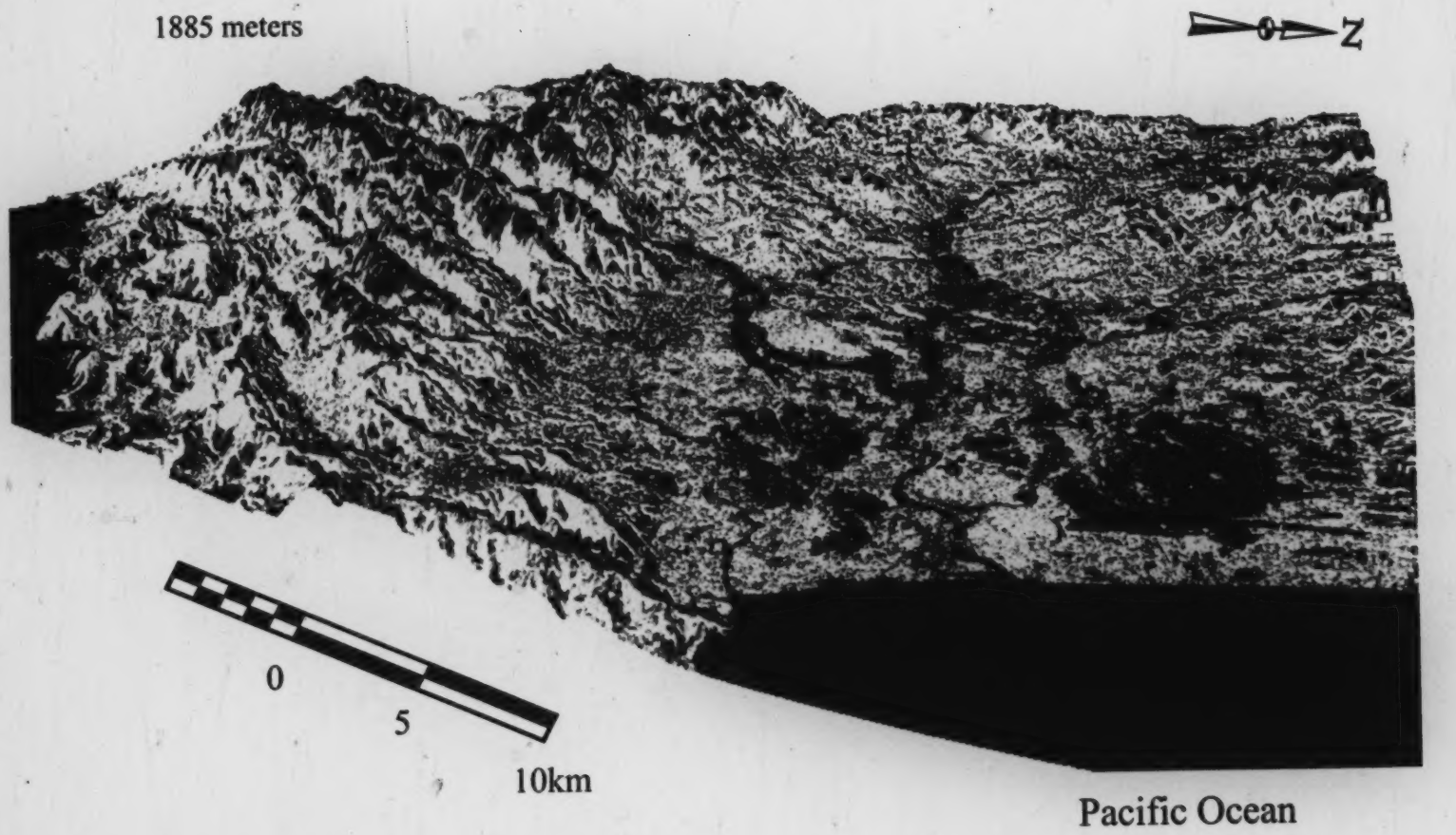


Figure 12. Three dimensional perspective of the JERS-1 image draped over the study area DEM.

4.3 Relationships Between Forest Density and JERS-1 Gray Level Values

4.3.1 Qualitative Analyses

The patterns of mean gray level values for the different forest density classes were studied for each slope magnitude + aspect class (Figure 13). For almost all the forest density classes, the mean pixel values are greatest for the steeper slopes (Slope Classes 5 and 6) with an aspect towards the imaging RADAR system (Aspect Class 1, also 2 and 8). In contrast, the mean pixel values are least for the lower slopes (Slope Classes 1, 2, and 3) and aspects away from the imaging system (Aspect Classes 4, 5, and 6). This pattern is related to the variations in intensity of energy incident with the land surfacen with greater levels of illumination on surfaces facing the satellite system and lower levels on the surfaces in the RADAR shadow. Also, the magnitude of the mean gray level values for aspects 2 and 8, 3 and 7, and 4 and 6, follow similar patterns for the different forest densities, indicating some symmetry to the data related to landscape orientation. The pattern of the data for the Grassland is much more variable than that for the data for the other forest densities, followed by the data for Mossy Forest (Figure 13). These two classes represent the areas of relatively short vegetation cover with lesser amounts of vegetative biomass above the ground surface than other forest densities. The longer wavelength L-band RADAR may be penetrating to the ground surface and the returns affected more by variations in ground surface affects than the other forest densities. The zero values for Grassland indicate slope magnitude + aspect combinations that were of limited extent in the area and therefore not sampled.

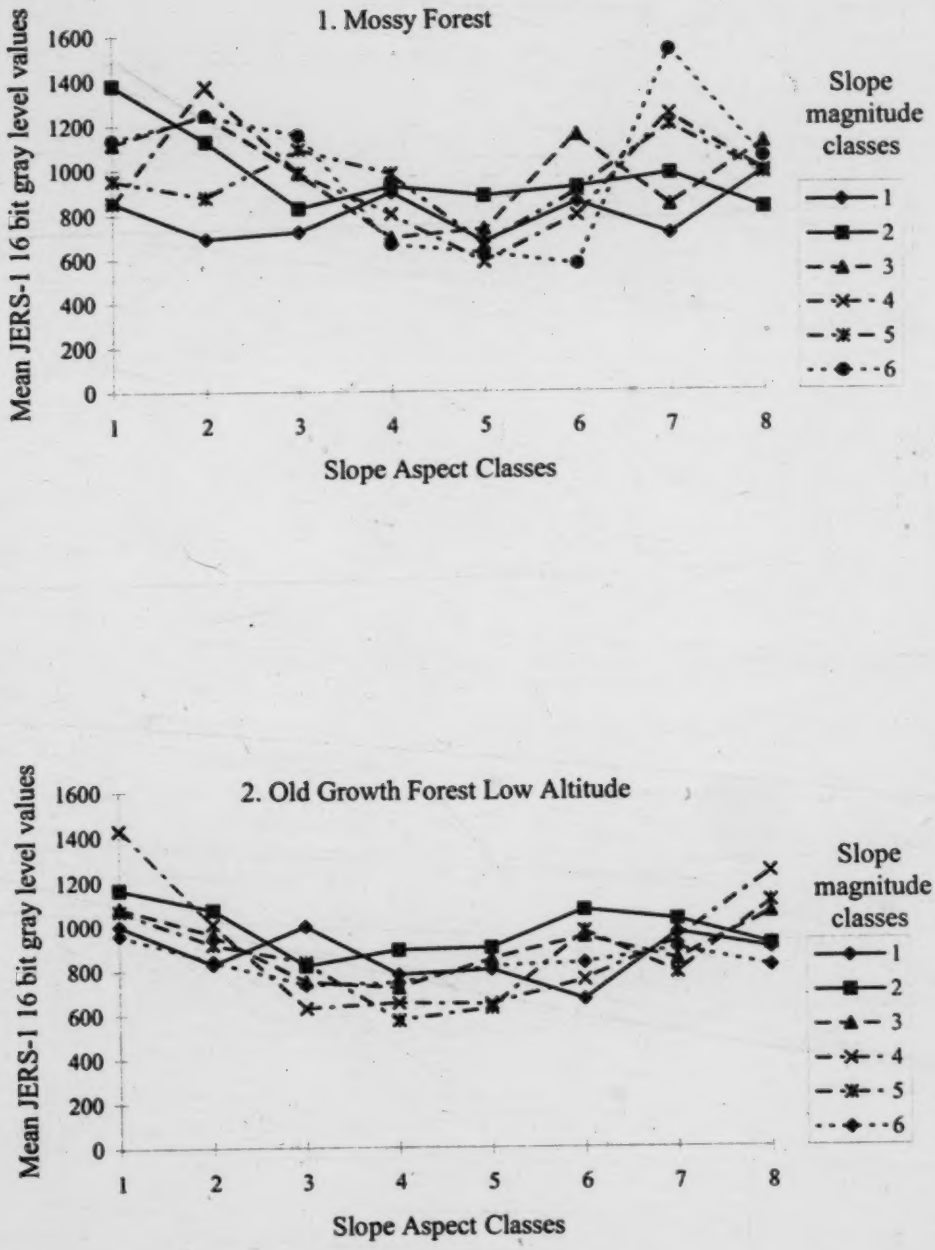
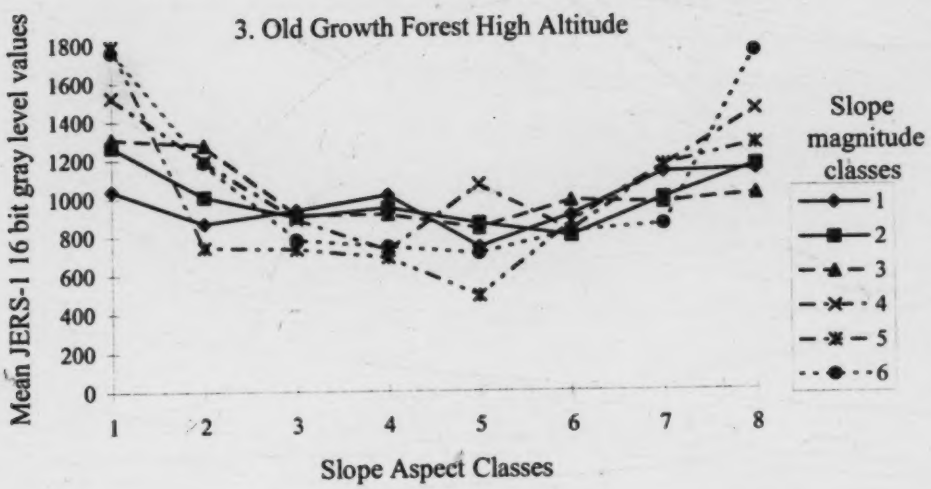


Figure 13. Patterns of mean JERS-1 gray level values for each slope aspect class from different slope classes, for the forest density classes.



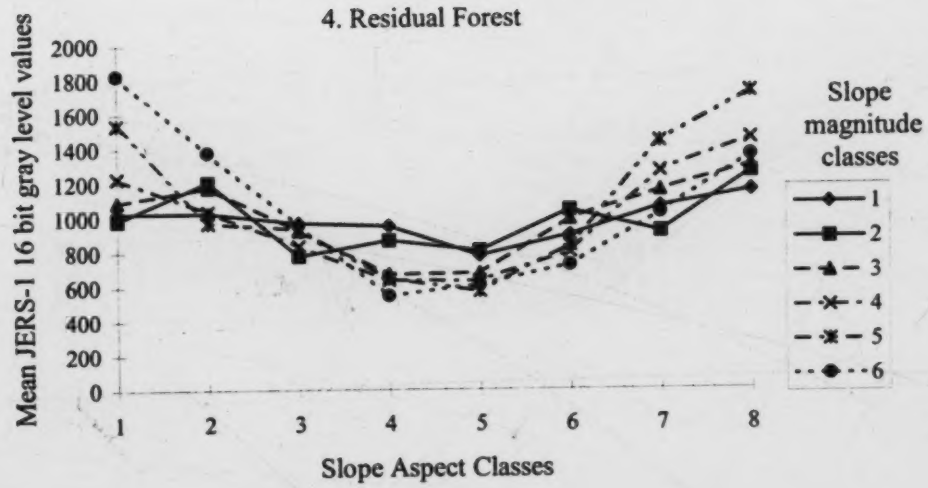
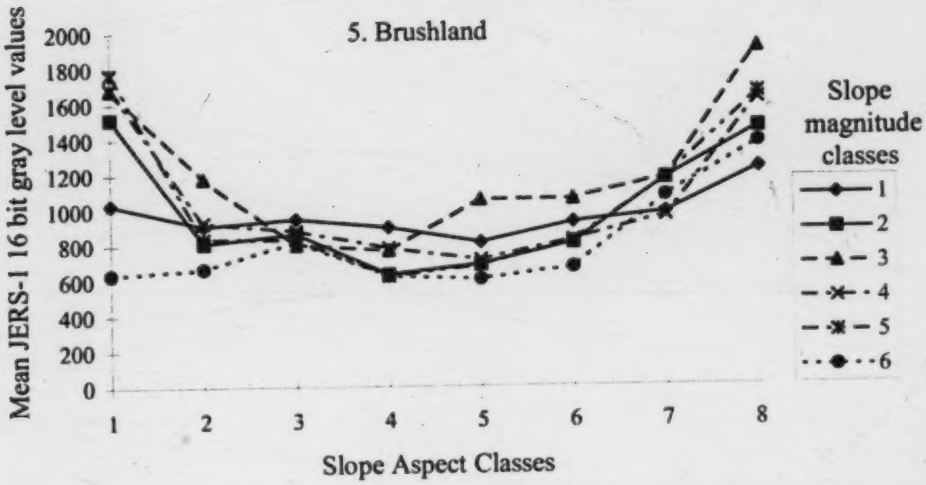


Figure 13. Patterns of mean JERS-1 gray level values for each slope aspect class from different slope classes, for the forest density classes (continued).



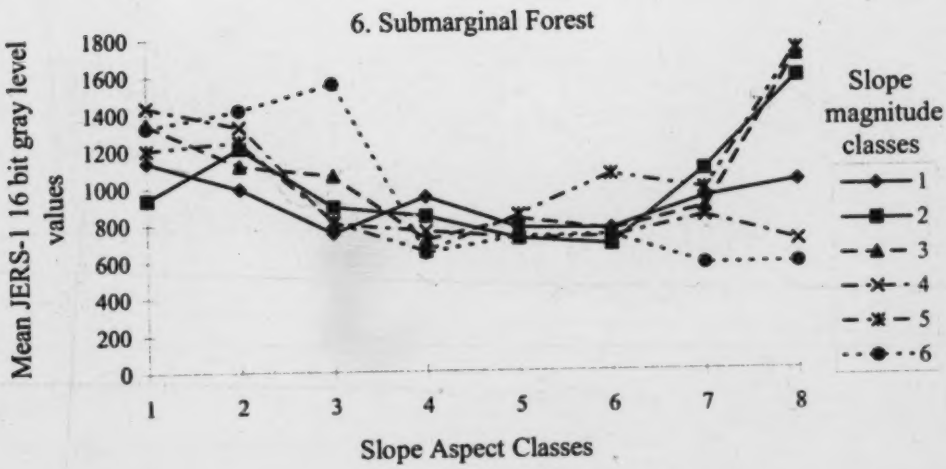


Figure 13. Patterns of mean JERS-1 gray level values for each slope aspect class from different slope classes, for the forest density classes (continued).

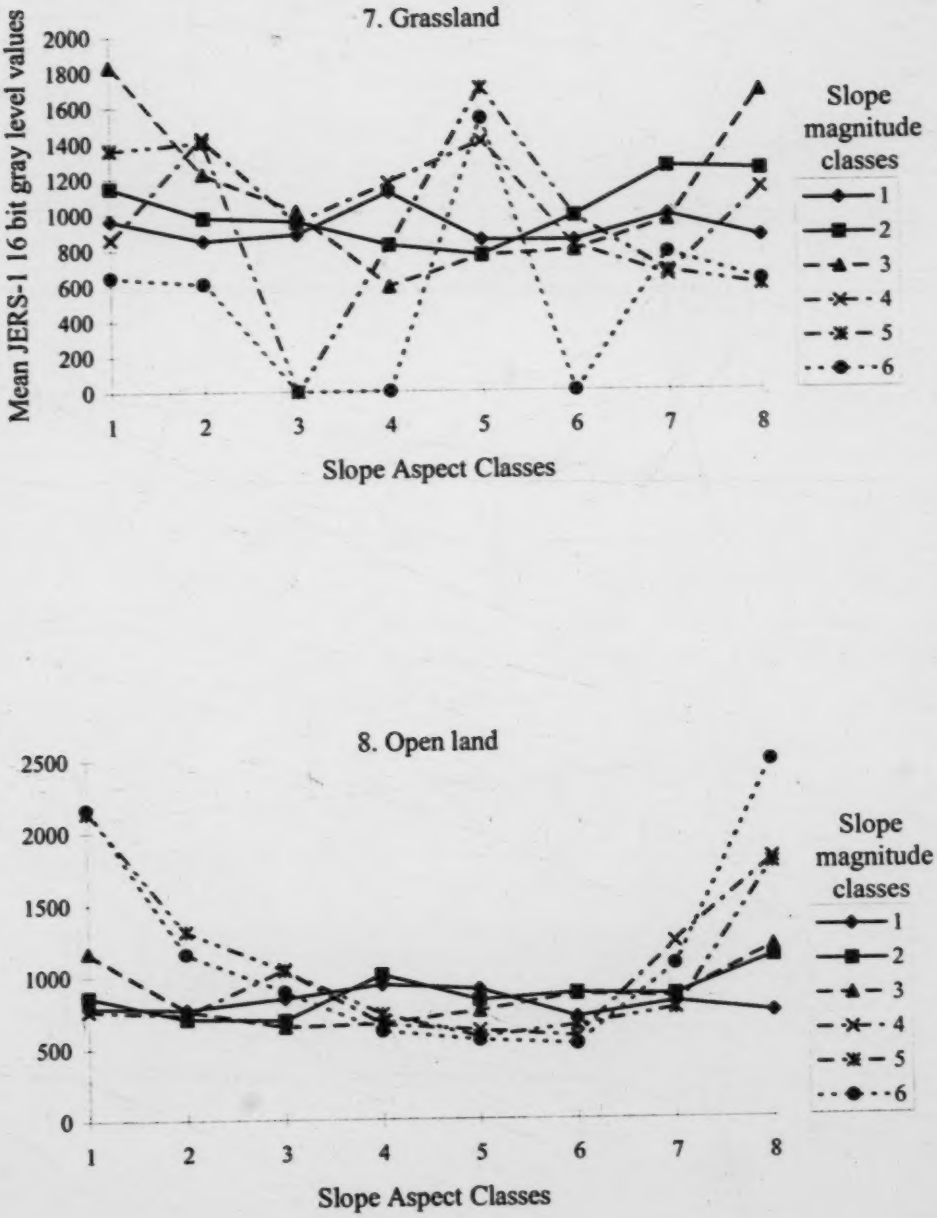


Figure 13. Patterns of mean JERS-1 gray level values for each slope aspect class from different slope classes, for the forest density classes (continued).

The patterns of standard deviation values associated with each of the means were also studied (Figure 14). There is a high degree of variability in the RADAR data associated with each forest density class on each of the slope magnitude + aspect combinations. This variability is evident as the speckle, or "salt and pepper pattern, in the RADAR image (Figure 11). It is the result of random constructive and destructive interference in the RADAR backscatter from complex reflecting surfaces in the target, producing random light and dark patterns in the image (Lillesand and Kiefer 1994).

For each density class the degree of variability, as indicated by the standard deviation, is generally less for aspects away from the sensor system (aspect classes 4, 5, 6) compared to those aspects facing the system (aspect classes 1, 2, 8). Also, the degree of variability indicated through the standard deviation values are greatest for the Mossy and Old Growth forests, and becomes less for the submarginal forest and the brushland, and appears to be relatively the lowest for the residual forest and open land (Figure 14). This may be related to the decreasing amount of complexity in the forest stand structure in the residual forest and brushland as there is less variation in tree height and stem diameter in these latter classes.

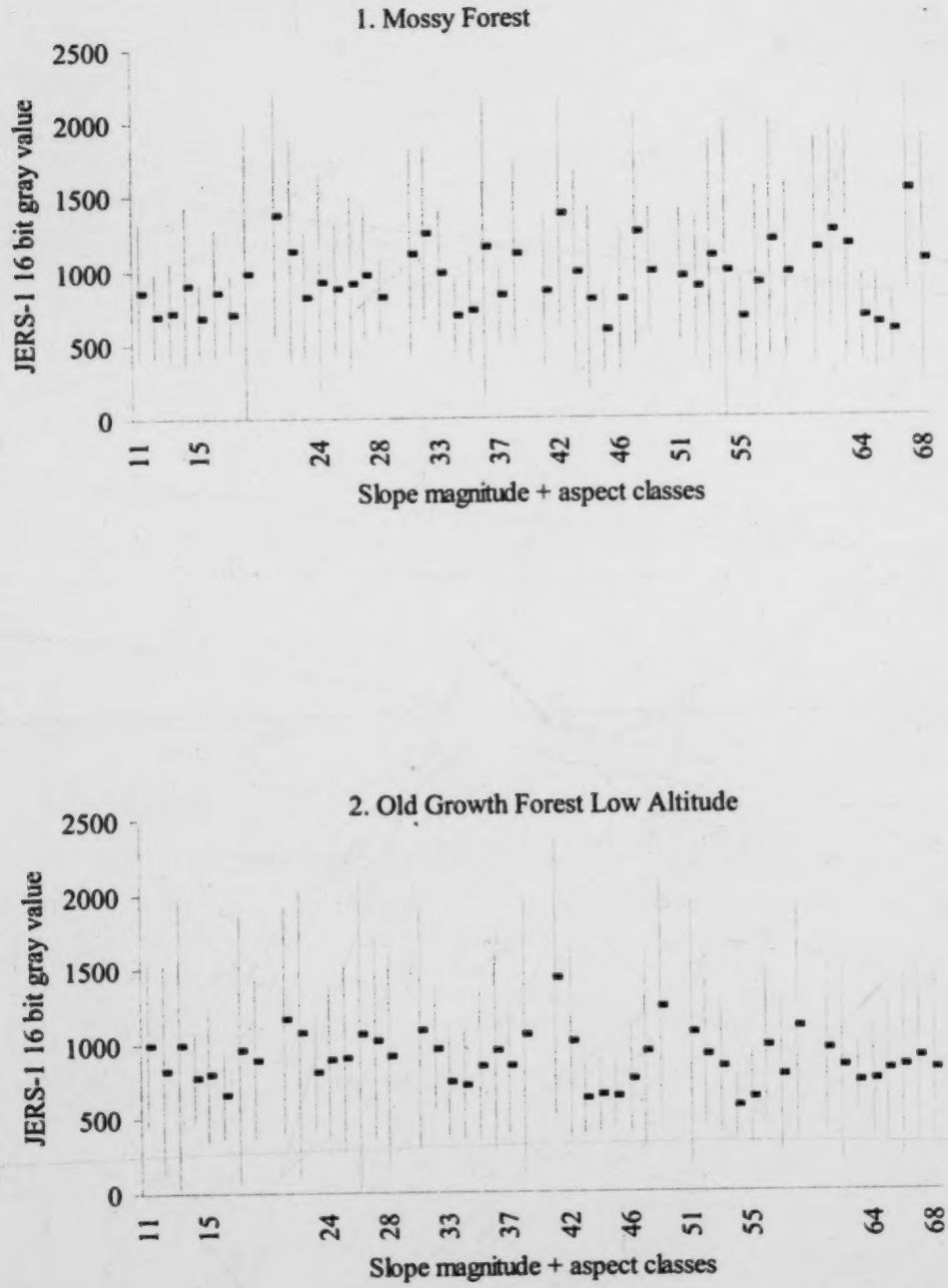
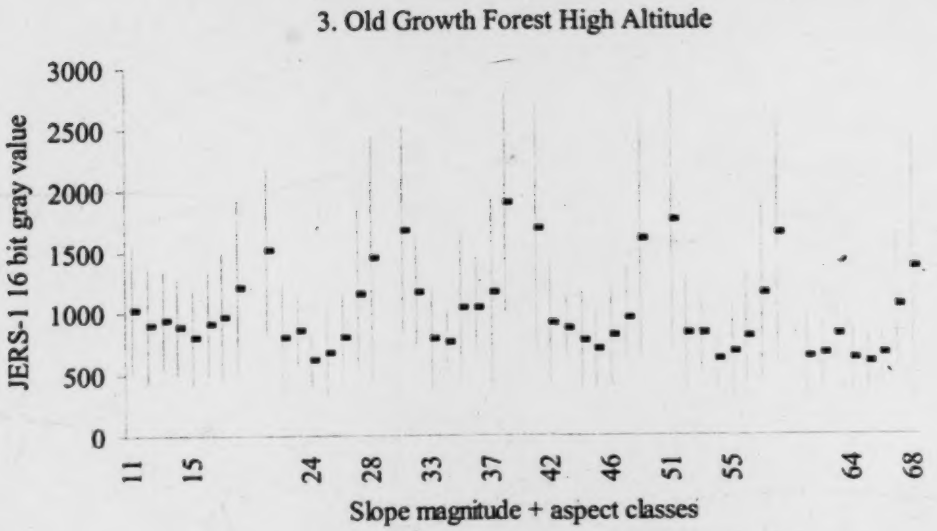


Figure 14. Mean and standard deviation of JERS-1 image gray level values for each slope magnitude + aspect class combination, for the forest density class.



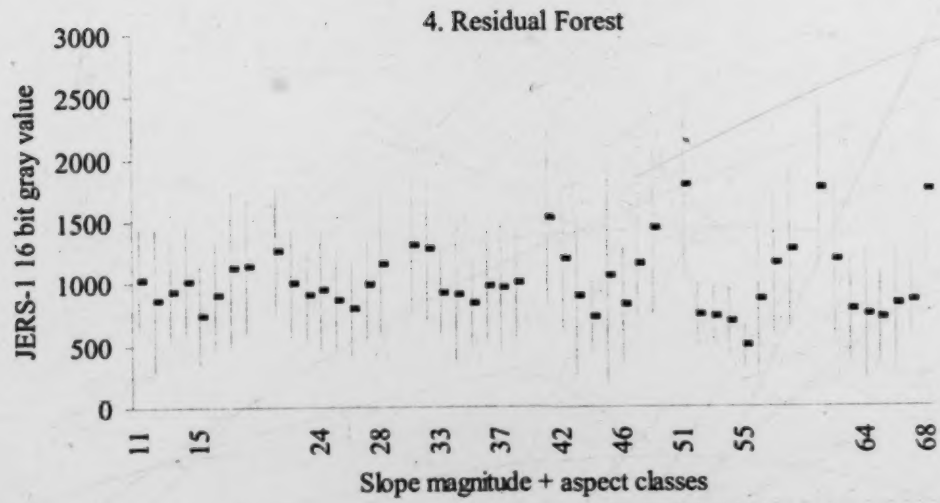
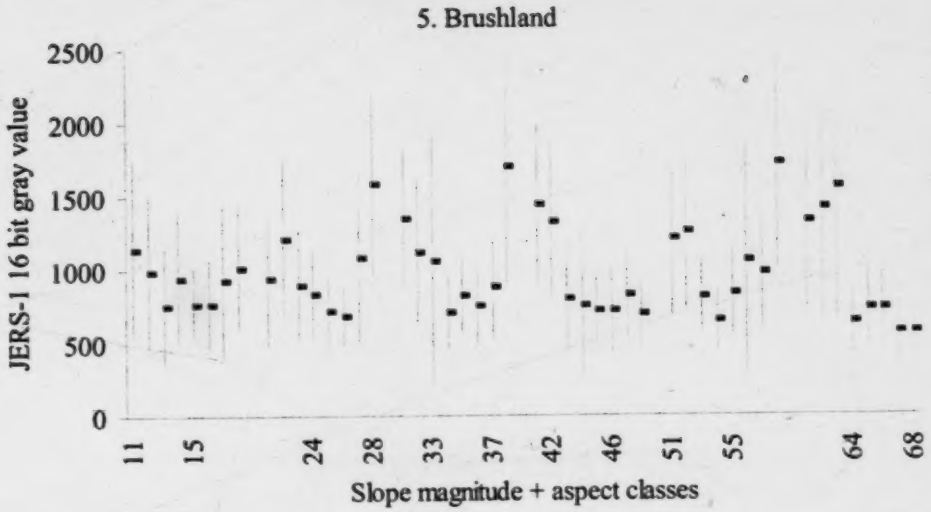


Figure 14. Mean and standard deviation of JERS-1 image gray level values for each slope magnitude + aspect class combination, for the forest density class (continued).



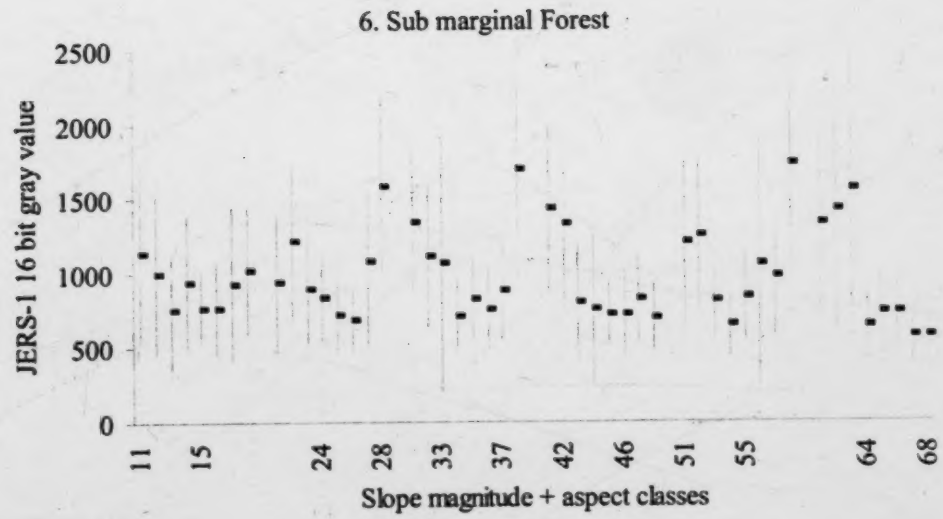
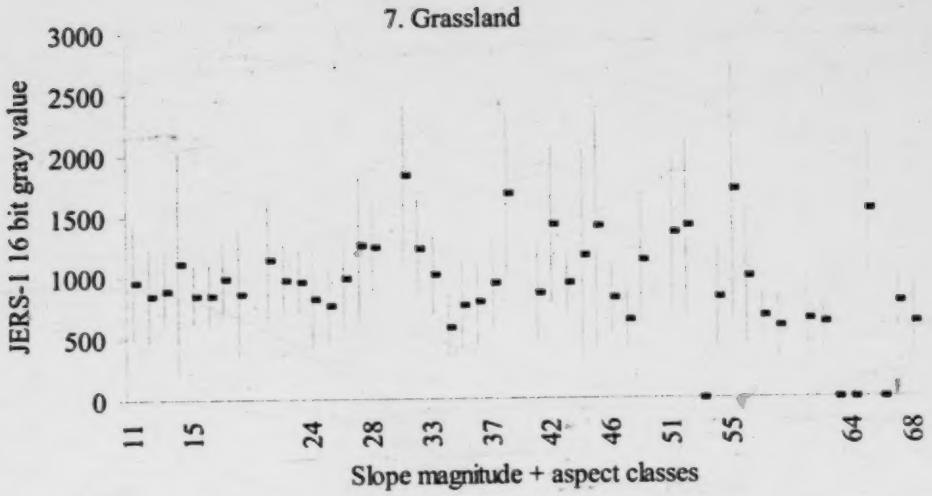


Figure 14. Mean and standard deviation of JERS-1 image gray level values for each slope magnitude + aspect class combination, for the forest density class (continued).



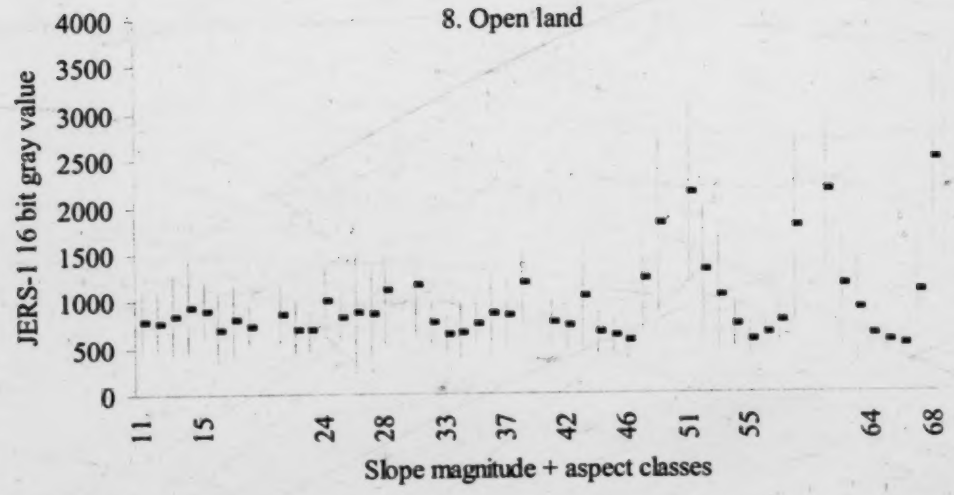


Figure 14. Mean and standard deviation of JERS-1 image gray level values for each slope magnitude + aspect class combination, for the forest density class (continued).

4.3.2 Statistical Analyses

To test the first hypothesis, the mean JERS-1 gray level value (GLV) for the forest density classes were tested for significant differences among them. The one-way analysis of variance that was performed revealed that, for the forest density classes alone, regardless of slope and aspect, there is a significant difference in RADAR image gray level values between the open land, old growth forest at low altitude, and mossy forest. The rest of the density classes, however, do not show any significant differences among each other and are confused (Table 9). The forest density classes that are confused are those having lower volumes of trees compared to the old growth forest in low altitude. The grassland class which is devoid of forest was also included in this group. A possible reason for the inclusion of this class is that there may not have been enough observations of grassland, especially in higher slopes, and thereby there is a bias towards classes on the lower ones. This is supported by the data presented in Table 8 in which the cover classes on the steeper slopes, slope magnitude classes 5 and 6, occupy only a very small proportion of the total study area.

The Open Land has the lowest mean gray level (backscatter) values which is understandable since these areas are smoother than the other density classes, and the transmitted microwave energy may be reflected in a specular fashion away from the sensor, unless the area is facing directly towards the energy source. The Old Growth forest in low altitude is significantly different because these areas have the thickest canopy among the forest densities. Mossy forest is segregated because the area is mostly found in the higher elevation and the canopy is relatively thinner compared to the other

Table 9. ANOVA table and Duncan's comparison test for differences between forest density classes regardless of slope magnitude and aspect.

Number of observations in data set = 14344

General Linear Models Procedure

Dependent Variable: LRADAR

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	7	47.603162	6.800452	71.05	0.0001
Error	14336	1372.066803	0.095708		
Corrected Total	14343	1419.669965			

R-Square	C.V.	Root MSE	LRADAR Mean
0.033531	10.64390	0.3094	2.9065

Alpha= 0.05 df= 14336 MSE= 0.095708

Duncan Grouping	Mean	N	GROUP
A	2.95265	1793	Brushland
A	2.94027	1793	Residual Forest
A	2.93774	1793	Old Growth Forest in High Elevation
A	2.93581	1793	Grassland
A	2.93396	1793	Sub marginal Forest
B	2.90472	1793	Mossy Forest
C	2.88225	1793	Old Growth Forest In Low Elevation
D	2.76473	1793	Open Land

forest densities. Another cause may be related to the dielectric constant, since this kind of forest is situated in areas of higher moisture content than areas of the other classes.

It is established from the General Linear Model (Table 9) that there are significant differences in mean JERS-1 RADAR gray level values among the forest densities. These differences however, may not be due to the forest densities alone, but to some other variables such as slope, aspect, or a combination of the two. In testing the significant differences of the densities, a General Linear Model was performed a second time to include these additional factors. A model which includes an interaction term among the density, slope and aspect is also considered (Table 10). This interaction term was included as there appears to be a relationship among the three variables (Telliet *et al.* 1985). To make the analysis simple, an additive model to test the interaction between the density classes among the slope, aspect, and combination of both is investigated. There is a significant contribution from the interaction among the three variables as shown in Table 10 as indicated by the increase in the R square values, which are the proportion of the variability in the backscatter explained by the model, to 0.48 for the density + slope magnitude + slope aspect, from 0.08 and 0.16 for the density + slope magnitude, and density + slope aspect, respectively.

4.3.3 Forest density classification with stratification from combined slope and aspect classes

The combination of the slope + aspect for the Duncans test results in significant differences for almost all of the combination classes (Table 11) which establishes the effects of these combined variables have on RADAR backscattering values. In the

Table 10. ANOVA with interaction terms by slope and aspect.

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	47	122.74631	2.61162	29.20	0.0001
Error	14296	1278.75859	0.08945		
Corrected Total	14343	1401.50489			

R-Square	C.V.	Root MSE	LRADAR Mean
0.087582	10.28871	0.2991	2.9069

Source	DF	Type III SS	Mean Square	F Value	Pr > F
GROUP	7	54.955542	7.850792	87.77	0.0001
SLOPE	5	21.394778	4.278956	47.84	0.0001
GROUP*SLOPE	35	55.187425	1.576784	17.63	0.0001

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	63	238.06410	3.77880	45.67	0.0001
Error	14280	1181.60587	0.08275		
Corrected Total	14343	1419.66996			

R-Square	C.V.	Root MSE	LRADAR Mean
0.167690	9.896907	0.2877	2.9065

Source	DF	Type III SS	Mean Square	F Value	Pr > F
GROUP	7	55.672721	7.953246	96.12	0.0001
ASPECT	7	97.220410	13.888630	167.85	0.0001
GROUP*ASPECT	49	93.240525	1.902868	23.00	0.0001

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	383	690.57731	1.80307	34.52	0.0001
Error	13960	729.09266	0.05223		
Corrected Total	14343	1419.66996			

R-Square	C.V.	Root MSE	LRADAR Mean
0.486435	7.862776	0.2285	2.9065

Source	DF	Type III SS	Mean Square	F Value	Pr > F	
GROUP	7	107.82335	15.40334	294.93	0.0001	
ASPECT	7	120.89152	17.27022	330.67	0.0001	
SLOPE	5	43.43886	8.68777	166.35	0.0001	
GROUP*ASPECT*SLOPE	364	515.83252	1.41712	27.13	0.0001	

SLOPE + ASPECT CLASS=11				SLOPE + ASPECT CLASS=12			
Grouping				Grouping			
	A		Submarginal Forest		A		Residual Forest
B	A		Brushland		A		Submarginal Forest
B	A	C	Old Growth High	B	A		Old Growth High
B	A	C	Residual Forest	B	A		Grassland
B	A	C	Old Growth Low	B	A		Brushland
B	A	C	Grassland	B	A		Open Land
B		C	Mossy Forest	B			Old Growth Low
		C	Open Land	B			Mossy Forest
SLOPE + ASPECT CLASS=13				**SLOPE + ASPECT CLASS=14**			
Grouping				Grouping			
	A		Residual Forest	A			Brushland
	A		Brushland	A			Residual Forest
	A		Old Growth High	A			Submarginal Forest
	A		Grassland	A			Grassland
B	A		Old Growth Low	A			Open Land
B	A		Open Land	A			Old Growth High
B			Submarginal Forest	A			Mossy Forest
B			Mossy Forest	A			Old Growth Low
SLOPE + ASPECT CLASS=15				**SLOPE + ASPECT CLASS=16**			
Grouping				Grouping			
	A		Open Land		A		Residual Forest
	A		Grassland		A		Old Growth High
B	A		Old Growth High		A		Brushland
B	A		Submarginal Forest		A		Grassland
B	A		Old Growth Low		A		Mossy Forest
B	A		Residual Forest	B	A		Submarginal Forest
B			Brushland	B			Open Land
B			Mossy Forest	B			Old Growth Low
SLOPE + ASPECT CLASS=17				**SLOPE + ASPECT CLASS=18**			
Grouping				Grouping			
	A		Brushland		A		Residual Forest
	A		Grassland		A		Old Growth High
	A		Residual Forest		A		Brushland
B	A		Old Growth High	B	A		Submarginal Forest
B	A	C	Submarginal Forest	B		C	Old Growth Low
B		C	Old Growth Low	B		C	Mossy Forest
B		C	Open Land	B		C	Grassland
		C	Mossy Forest			C	Open Land

Table 11. Duncan's multiple comparison test for significant differences between mean JERS-1 gray level values for forest density classes within slope magnitude + aspect classes. Forest classes with same group letter are not significantly different at 0.05 level. First digit of class number indicates slope magnitude class, the second the aspect class.

SLOPE + ASPECT CLASS=21			
Grouping			
	A		Old Growth High
B	A		Mossy Forest
B	A		Brushland
B		C	Grassland
B		C D	Old Growth Low
		C D	Residual Forest
		C D	Submarginal Forest
		D	Open Land

SLOPE + ASPECT CLASS=22	
Grouping	
A	Submarginal Forest
A	Residual Forest
A	Mossy Forest
A	Grassland
A	Brushland
A	Old Growth Low
B	Old Growth High
B	Open Land

SLOPE + ASPECT CLASS=23			
Grouping			
	A		Grassland
B	A		Brushland
B	A		Old Growth High
B	A		Submarginal Forest
B		C	Old Growth Low
B		C	Mossy Forest
B		C	Residual Forest
		C	Open Land

SLOPE + ASPECT CLASS=24	
Grouping	
A	Open Land
A	Brushland
A	Submarginal Forest
A	Residual Forest
A	Mossy Forest
A	Old Growth Low
A	Grassland
B	Old Growth High

SLOPE + ASPECT CLASS=25			
Grouping			
	A		Open Land
	A		Brushland
	A		Old Growth Low
	A		Mossy Forest
B	A		Residual Forest
B	A		Grassland
B	A		Submarginal Forest
B			Old Growth High

SLOPE + ASPECT CLASS=26			
Grouping			
		A	Residual Forest
B	A		Grassland
B	A	C	Old Growth Low
B	A	C	Mossy Forest
B	A	C	Old Growth High
B		C	Open Land
		C	Brushland
		C	Submarginal Forest

SLOPE + ASPECT CLASS=27			
Grouping			
	A		Grassland
B	A		Old Growth High
B	A	C	Submarginal Forest
B	A	C	Mossy Forest
B	A	C	Brushland
B		C	Residual Forest
B		C	Old Growth Low
		C	Open Land

SLOPE + ASPECT CLASS=28			
Grouping			
		A	Submarginal Forest
B	A		Grassland
B	A		Old Growth High
B			Residual Forest
B			Brushland
B			Open Land
		C	Mossy Forest
		C	Old Growth Low

Table 11. Duncan's multiple comparison test for significant differences between mean JERS-1 gray level values for forest density classes within slope magnitude + aspect classes. Forest density classes with same group letter are not significantly different at 0.05 level (continued).

SLOPE + ASPECT CLASS=31	
Grouping	
A	Grassland
B A	Old Growth High
B C	Submarginal Forest
B C D	Brushland
E C D	Open Land
E D	Residual Forest
E	Mossy Forest
E	Old Growth Low

SLOPE + ASPECT CLASS=32	
Grouping	
A	Brushland
A	Grassland
A	Mossy Forest
A	Old Growth High
A	Residual Forest
B A	Submarginal Forest
B	Old Growth Low
C	Open Land

SLOPE + ASPECT CLASS=33	
Grouping	
A	Grassland
A	Mossy Forest
B A	Residual Forest
B A	Brushland
B A	Submarginal Forest
B C	Old Growth High
C	Old Growth Low
C	Open Land

SLOPE + ASPECT CLASS=34	
Grouping	
A	Brushland
B A	Old Growth High
B A C	Submarginal Forest
B C	Old Growth Low
B C	Mossy Forest
B C	Residual Forest
B C	Open Land
C	Grassland

SLOPE + ASPECT CLASS=35	
Grouping	
A	Old Growth High
B A	Submarginal Forest
B C	Brushland
B C	Old Growth Low
B C	Open Land
B C	Grassland
B C	Mossy Forest
C	Residual Forest

SLOPE + ASPECT CLASS=36	
Grouping	
A	Old Growth High
B A	Mossy Forest
B A	Brushland
B A	Residual Forest
B A	Old Growth Low
B A	Open Land
B	Grassland
B	Submarginal Forest

SLOPE + ASPECT CLASS=37	
Grouping	
A	Old Growth High
B A	Residual Forest
B A	Grassland
B A	Brushland
B A	Submarginal Forest
B	Mossy Forest
B	Open Land
B	Old Growth Low

SLOPE + ASPECT CLASS=38	
Grouping	
A	Old Growth High
A	Grassland
A	Submarginal Forest
B	Residual Forest
C B	Open Land
C B D	Mossy Forest
C D	Brushland
D	Old Growth Low

Table 11. Duncan's multiple comparison test for significant differences between mean JERS-1 gray level values for forest density classes within slope magnitude + aspect classes. Forest density classes with same group letter are not significantly different at 0.05 level (continued).

SLOPE + ASPECT CLASS=41			SLOPE + ASPECT CLASS=42		
Grouping			Grouping		
	A	Old Growth High		A	Grassland
B	A	Brushland		A	Submarginal Forest
B	A	Submarginal Forest		A	Mossy Forest
B	A	Old Growth Low	B	A	Brushland
B		Residual Forest	B	C	Residual Forest
	C	Grassland	D	C	Old Growth Low
	C	Mossy Forest	D	C	Old Growth High
	C	Open Land	D		Open Land
SLOPE + ASPECT CLASS=43			**SLOPE + ASPECT CLASS=44**		
Grouping			Grouping		
A		Mossy Forest	A		Grassland
A		Grassland	B		Old Growth High
A		Old Growth High	B		Brushland
A		Submarginal Forest	B		Mossy Forest
A		Brushland	B		Submarginal Forest
A		Residual Forest	B		Open Land
A		Old Growth Low	B		Old Growth Low
B		Open Land	B		Residual Forest
SLOPE + ASPECT CLASS=45			**SLOPE + ASPECT CLASS=46**		
Grouping			Grouping		
	A	Grassland	A		Grassland
	B	Brushland	A		Old Growth High
C	B	Submarginal Forest	A		Brushland
C	D	Old Growth High	A		Residual Forest
C	D	Old Growth Low	A		Mossy Forest
C	D	Residual Forest	A		Old Growth Low
C	D	Open Land	A		Submarginal Forest
	D	Mossy Forest	B		Open Land
SLOPE + ASPECT CLASS=47			**SLOPE + ASPECT CLASS=48**		
Grouping			Grouping		
	A	Residual Forest		A	Open Land
	A	Open Land	B	A	Old Growth High
B	A	Mossy Forest	B	A	Brushland
B	A	Brushland	B	C	Residual Forest
B	C	Old Growth High	B	C	Old Growth Low
	C	Old Growth Low		C	Grassland
	C	Submarginal Forest		C	Mossy Forest
	D	Grassland		D	Submarginal Forest

Table 11. Duncan's multiple comparison test for significant differences between mean JERS-1 gray level values for forest density classes within slope magnitude + aspect classes. Forest density classes with same group letter are not significantly different at 0.05 level (continued).

SLOPE + ASPECT CLASS=51				SLOPE + ASPECT CLASS=52	
Grouping				Grouping	
	A		Open Land	A	Grassland
B	A		Brushland	A	Submarginal Forest
B	C		Old Growth High	A	Open Land
B	C	D	Residual Forest	B	Old Growth Low
	C	D	Grassland	B	Residual Forest
	E	D	Submarginal Forest	B	Mossy Forest
	E		Old Growth Low	B	Old Growth High
	E		Mossy Forest	B	Brushland
SLOPE + ASPECT CLASS=53				**SLOPE + ASPECT CLASS=54**	
Grouping				Grouping	
	A		Grassland	A	Grassland
B	A		Old Growth Low	A	Mossy Forest
B	A		Residual Forest	A	Brushland
B	A		Submarginal Forest	A	Old Growth High
B	A		Old Growth High	A	Submarginal Forest
B	A		Mossy Forest	A	Residual Forest
B			Brushland	A	Old Growth Low
	C		Open Land	B	Open Land
SLOPE + ASPECT CLASS=55				**SLOPE + ASPECT CLASS=56**	
Grouping				Grouping	
	A		Grassland	A	Grassland
	B		Submarginal Forest	A	Submarginal Forest
	C		Mossy Forest	A	Old Growth Low
	C		Old Growth High	A	Mossy Forest
	C		Old Growth Low	A	Residual Forest
D	C		Residual Forest	A	Brushland
D	C		Open Land	B	A Old Growth High
D			Brushland	B	Open Land
SLOPE + ASPECT CLASS=57				**SLOPE + ASPECT CLASS=58**	
Grouping				Grouping	
	A		Residual Forest	A	Submarginal Forest
	A		Brushland	A	Residual Forest
B	A		Old Growth High	A	Open Land
B	A		Mossy Forest	B	A Old Growth High
B	A	C	Submarginal Forest	B	C Brushland
B		C	Old Growth Low	D	C Old Growth Low
	D	C	Grassland	D	Mossy Forest
	D		Open Land	E	Grassland

Table 11. Duncan's multiple comparison test for significant differences between mean JERS-1 gray level values for forest density classes within slope magnitude + aspect classes. Forest density classes with same group letter are not significantly different at 0.05 level (continued).

SLOPE + ASPECT CLASS=61		SLOPE + ASPECT CLASS=62	
Grouping		Grouping	
A	Open Land	A	Submarginal Forest
B A	Brushland	B A	Brushland
B	Residual Forest	B A	Mossy Forest
C	Submarginal Forest	B A	Grassland
D C	Mossy Forest	B A	Residual Forest
D	Old Growth Low	B A	Old Growth Low
E	Grassland	B	Old Growth High
E	Old Growth High	C	Open Land
SLOPE + ASPECT CLASS=63		**SLOPE + ASPECT CLASS=64**	
Grouping		Grouping	
A	Submarginal Forest	A	Brushland
B	Mossy Forest	A	Submarginal Forest
C B	Old Growth High	A	Old Growth High
C	Grassland	A	Old Growth Low
C	Old Growth Low	A	Mossy Forest
C	Residual Forest	A	Residual Forest
C	Brushland	B	Grassland
D	Open Land	C	Open Land
SLOPE + ASPECT CLASS=65		**SLOPE + ASPECT CLASS=66**	
Grouping		Grouping	
A	Grassland	A	Old Growth Low
B	Old Growth Low	B A	Submarginal Forest
B	Submarginal Forest	B A	Residual Forest
B	Brushland	B A	Brushland
B	Old Growth High	B A	Old Growth High
B	Mossy Forest	B C	Mossy Forest
B	Residual Forest	C	Grassland
C	Open Land	D	Open Land
SLOPE + ASPECT CLASS=67		**SLOPE + ASPECT CLASS=68**	
Grouping		Grouping	
A	Mossy Forest	A	Open Land
B	Old Growth High	B	Brushland
B	Open Land	C	Residual Forest
B	Residual Forest	D C	Old Growth High
B	Brushland	D E	Mossy Forest
B	Old Growth Low	F E	Old Growth Low
B	Grassland	F	Submarginal Forest
C	Submarginal Forest	F	Grassland

Table 11. Duncan's multiple comparison test for significant differences between mean JERS-1 gray level values for forest density classes within slope magnitude + aspect classes. Forest density classes with same group letter are not significantly different at 0.05 level (continued).

relatively flat areas, less than 9 degrees slope magnitude (Table 11; classes 11, 12, 13, 14, 15, 16, 17, 18), there is statistical confusion in segregating the different densities. This could be generalized up to the slopes less than 30 degrees magnitude except in slope magnitude + aspect class 24 where the old growth forest was differentiated from the rest of the density classes. As the slope magnitude increases beyond 30 degrees, the ability to distinguish some density classes, particularly the non-forested classes, of open land and grassland also increased. Some forest density classes such as brushland and submarginal forest were also differentiated from the rest of the density classes.

Interestingly, the aspect classes which are directly facing the RADAR antennae (Table 11; classes 11, 21, 31, 41, 51, and 61) show a high confusion between density classes and did not allow for differentiation of any of the density classes regardless of slope magnitude. This aspect class which is oriented to the RADAR source must have so much energy that resulted in not being able to distinguish any of the density classes. The higher mean gray level values (Figure 13) and greater standard deviations (Figure 14) for these aspects assist in the explanation of statistical confusion. Details of the Duncan's comparison test are included in Appendix 2.

4.4 Summary

The two major concerns for the forests in Aurora Province, the Philippines, are the illegal harvesting of selected large trees, and the complete clearing of trees from small land parcels. The largest trees would be found in the old growth forest areas. After harvesting, these old growth forest areas may take on the stand structure and geometry

characteristics of residual forest areas. In this study, the discrimination of old growth forest from residual forest is very poor. There is no significant differences between the old growth forests (either high altitude, low altitude, or both) and the residual forest areas in any of the Duncan's comparisons (Table 11).

The clearing of land should result in areas of any of the forest classes being similar in vegetation density to either the grassland or the open density classes. Significant differences between either grassland or open classes and the forest classes occur only for some of the slope + aspect combinations, generally those on slopes greater than 30 degrees and all aspects other than those directly toward the satellite RADAR system.

Chapter 5. CONCLUSION

5.1 Synthesis

This study was conducted to evaluate the relationship between forest densities and RADAR backscattering values, specifically using JERS-1 SAR data. The selection of this RADAR imagery was due to consideration of its parameters, particularly the longer wavelength of 23.5 centimeters which compared to C-band, is more effective in penetrating the forest canopy. Therefore, it would provide more variations in information with respect to forest density. The HH polarization and the incidence angle of 35 degrees were parameters especially suited to this type of study.

The use of a digital elevation model (DEM) is shown as very important in the geometric correction of RADAR imagery specially in the areas with hilly or mountainous terrain. The layover and shadowing that severely affect the geometry of the RADAR image and surface orientation of the terrain. The geometric correction process resulted in altered gray level values for high altitude steeply sloping areas facing the satellite system. Although nearest neighbor resampling was employed in the alteration to the geometry the layover areas were stretched back to cover larger areas at the tops and sides of the steeper slopes.

Forest monitoring will be difficult to undertake using the JERS-1 SAR data alone. This study has shown that slight change in forest density such as the old growth forest and a residual forest cannot be easily differentiated. This means that when the forest is disturbed by logging through selective means, the area may be confused with some other density classes such as submarginal forest or brushland or vice versa. The same thing will

be true of old growth forest in higher altitude, which will be confused with the old growth in low altitudes. These are essentially two different classes considering the stand volume that relates to biomass that previous researchers were able to differentiate. The changes in forest composition that result from selective logging, may be identified through studies of changes in the standard deviations associated with the sampled data rather than comparison of mean gray level values. There is less variability in the sample data from residual forests than for old growth forests and this may provide the monitoring approach.

It may be possible though to identify and segregate slash and burn farming. This is because the forest in the farmed area is totally removed, and from the point of view of forest density classification, it is classified an open land. Two general conditions however, have to be met in order to achieve this goal:

1) The aspect orientation should not be directly facing the energy source, which in this case, at 98 degrees east and at 45 degree angle; and
2) The slope should not be below 30 degrees or it may be confused with the other classes. This is considering that the area would at least be larger than the pixel size on the ground to be identified.

It is also observed, and established from previous reported research, that the surface which directly faces the RADAR source exhibits stronger reflections while areas facing away from the RADAR and level areas exhibit lower returns. This however, is not true to the same extent for in all forest density classes because the geometry and biomass of the vegetation changes the backscatter values recorded. The mean and standard deviation gray level values for the sampled pixels do not provide differentiation among forest densities facing the RADAR nor slopes that are generally flat irrespective of aspect

orientation. It is therefore necessary that in forest monitoring using the JERS-1 RADAR data, care should be taken to consider all of the limitations. The terrain factors such as slope and aspect should always be accounted for, even in future research.

5.2 Future Work

Future studies similar to this research would provide interesting results where:

- The same procedure may be carried out to gather information, but implemented in areas where different forest structures are present. It may come out to be applicable to a specific kind of forest and terrain. Different slope magnitude and aspect class limits may also be considered.
- Other spaceborne RADAR's such as ERS-1 and RADARSAT with shorter wavelengths and different polarizations would probably provide a different approach in examining forest density. The different incidence angle and resolution of RADARSAT would have a substantial effect on the backscatter values.
- It may also be possible to study the forest density classification from the view point of the RADAR backscatter values and classify the forest densities accordingly rather than be based from aerial photography.
- It may be important to observe changes in the forest density by using an image with the same parameter as the JERS-1 taken over the same area a few years later to provide change detection information.
- Instead of using the raw data, a study may be conducted with different filtering algorithms to illustrate and observe the effects.

- Contextual classification may also be used instead of random selection of samples, where the basis of classification is on the histogram of the neighboring pixels rather than just the average values.

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Chapter 7 APPENDICES

Appendix 1. Report on Ground Control Points from PCI

Set 2 Units:PIXEL Set 1 Units:PIXEL Number GCPs: 18

Model Parameters		FX	FY
1	CONS	-.154487E+03	.378155E+04
2	X	.937483E+00	-.138487E+01
3	Y	.147829E+01	-.165633E+00
4	X * Y	-.530710E-03	.284670E-03
5	X**2	-.641532E-03	.275665E-03
6	Y**2	-.233504E-03	.147903E-03
7	X**2 * Y	.228608E-06	-.120754E-06
8	X * Y**2	.118550E-06	-.757113E-07
9	X**3	.183615E-06	-.926725E-07
10	Y**3	.695771E-07	-.578985E-07
11	X**2 * Y**2	-.252154E-10	.471589E-10
12	X**3 * Y	-.291648E-10	-.286266E-11
13	X * Y**3	-.793693E-11	-.133818E-10
14	X**4	-.184654E-10	.145704E-10
15	Y**4	-.888813E-11	.122390E-10

GCP's are ordered from worst to best residuals.

GCP No.	Set 2 GCP's (PIXEL)		Set 1 GCP's (PIXEL)		Residual (PIXEL)		Distance
13	1008.4,	1864.4)	2250.6,	2677.4)	.42,	-.53)	.68
6	540.5,	2245.5)	2628.5,	3176.5)	-.51,	.37)	.63
14	1924.6,	1544.8)	1935.6,	1728.4)	-.22,	.43)	.49
18	531.6,	2778.6)	3181.1,	3243.4)	.38,	-.26)	.46
17	2698.6,	1490.4)	1928.4,	893.4)	.34,	-.26)	.43
5	947.6,	3072.7)	3500.7,	2791.4)	-.27,	.14)	.31
11	1851.4,	994.4)	1364.4,	1773.3)	-.14,	-.12)	.18
4	1889.6,	3030.4)	3503.4,	1780.4)	.14,	-.08)	.16
10	1896.6,	414.6)	770.4,	1694.1)	.14,	-.05)	.15
1	2782.6,	773.4)	1179.6,	794.4)	-.12,	.09)	.15
16	1050.6,	2543.6)	2961.3,	2640.4)	.10,	.09)	.14
2	2903.6,	2034.6)	2500.4,	725.4)	-.11,	.08)	.13
15	2081.4,	2373.6)	2826.6,	1579.6)	-.12,	-.04)	.13
12	892.4,	1150.6)	1515.6,	2768.6)	.02,	.12)	.12
9	700.4,	416.4)	725.4,	2923.4)	-.10,	.05)	.11
8	189.6,	747.4)	944.4,	3495.7)	.07,	-.05)	.08
3	2427.4,	2908.6)	3387.6,	1263.3)	-.01,	.02)	.03
7	418.9,	1443.9)	1775.3,	3267.1)	.00,	.00)	.00

Residual Plot (PIXEL): RMS=(.56, .53) .77

Appendix 2. ANOVA for Slope + Aspect class and Density

The SAS System

General Linear Models Procedure
Class Level Information

NOTE: This test controls the type I comparisonwise error rate, not the experimentwise error rate

Means with the same letter are not significantly different.

Class GROUP (Forest Densities)

Levels 8

Values - Brushland, RESIDUAL FOREST, OLD GROWTH FOREST-LOW (elevation), OLD GROWTH FOREST-HIGH (elevation) Grassland, Mossy Forest, Open Land, Submarginal Forest

---------- **SLOPE + ASPECT CLASS=11** ----------

Number of observations in by Group = 320

Dependent Variable: LRADAR

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	7	0.6526334	0.0932333	1.92	0.0663
Error	312	15.1673177	0.0486132		
Corrected Total	319	15.8199511			

R-Square	C.V.	Root MSE	LRADAR Mean
0.041254	7.507136	0.2205	2.9370

Source	DF	Type III SS	Mean Square	F Value	Pr > F
GROUP	7	0.6526334	0.0932333	1.92	0.0663

Duncan's Multiple Range Test for variable: LRADAR

Alpha= 0.05 df= 312 MSE= 0.048613

Number of Means	2	3	4	5	6	7	8
Critical Range	.0970	.1021	.1055	.1081	.1100	.1116	.1130

Duncan Grouping			Mean	N	GROUP
	A		2.99416	40	Submarginal Forest
B	A		2.98197	40	Brushland
B	A	C	2.95496	40	OLD GROWTH FOREST-HIGH
B	A	C	2.95378	40	RESIDUAL FOREST
B	A	C	2.94557	40	OLD GROWTH FOREST-LOW
B	A	C	2.93335	40	Grassland
B		C	2.87783	40	Mossy Forest
		C	2.85433	40	Open Land

---------- SLOPE + ASPECT CLASS=12----------

Number of observations in by Group = 320

Dependent Variable: LRADAR

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	7	0.7750567	0.1107224	2.28	0.0283
Error	312	15.1702100	0.0486225		
Corrected Total	319	15.9452668			

R-Square	C.V.	Root MSE	LRADAR Mean
0.048607	7.655702	0.2205	2.8803

Source	DF	Type III SS	Mean Square	F Value	Pr > F
GROUP	7	0.7750567	0.1107224	2.28	0.0283

Duncan's Multiple Range Test for variable: LRADAR

Alpha= 0.05 df= 312 MSE= 0.048622

Number of Means	2	3	4	5	6	7	8
Critical Range	.0970	.1021	.1056	.1081	.1100	.1116	.1130

Duncan Grouping	Mean	N	GROUP
A	2.95378	40	RESIDUAL FOREST
A	2.94725	40	Submarginal Forest
B A	2.90312	40	OLD GROWTH FOREST-HIGH
B A	2.88895	40	Grassland
B A	2.85410	40	Brushland
B A	2.85268	40	Open Land
B	2.83621	40	OLD GROWTH FOREST-LOW
B	2.80609	40	Mossy Forest

---------- SLOPE + ASPECT CLASS=13 ----------

Number of observations in by Group = 320

Dependent Variable: LRADAR

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	7	0.6519633	0.0931376	2.33	0.0246
Error	312	12.4453152	0.0398888		
Corrected Total	319	13.0972784			

R-Square	C.V.	Root MSE	LRADAR Mean
0.049779	6.897816	0.1997	2.8954

Source	DF	Type III SS	Mean Square	F Value	Pr > F
GROUP	7	0.6519633	0.0931376	2.33	0.0246

Duncan's Multiple Range Test for variable: LRADAR

Alpha= 0.05 df= 312 MSE= 0.039889

Number of Means	2	3	4	5	6	7	8
Critical Range	.0879	.0925	.0956	.0979	.0997	.1011	.1023

Duncan Grouping	Mean	N	GROUP
A	2.94287	40	RESIDUAL FOREST
A	2.93586	40	Brushland
A	2.93565	40	OLD GROWTH FOREST-HIGH
A	2.92208	40	Grassland
B A	2.89607	40	OLD GROWTH FOREST-LOW
B A	2.88055	40	Open Land
B	2.82644	40	Submarginal Forest
B	2.82398	40	Mossy Forest

---------- SLOPE + ASPECT CLASS=14 ----------

Number of observations in by Group = 320

Dependent Variable: LRADAR

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	7	0.2982708	0.0426101	0.87	0.5338
Error	312	15.3532108	0.0492090		
Corrected Total	319	15.6514815			

R-Square	C.V.	Root MSE	LRADAR Mean
0.019057	7.605749	0.2218	2.9166

Source	DF	Type III SS	Mean Square	F Value	Pr > F
GROUP	7	0.2982708	0.0426101	0.87	0.5338

Duncan's Multiple Range Test for variable: LRADAR

Alpha= 0.05 df= 312 MSE= 0.049209

Critical Range	.0976	.1027	.1062	.1087	.1107	.1123	.1137

Means with the same letter are not significantly different.

Duncan Grouping	Mean	N	GROUP
A	2.96080	40	Brushland
A	2.94252	40	RESIDUAL FOREST
A	2.93208	40	Submarginal Forest
A	2.92993	40	Grassland
A	2.91528	40	Open Land
A	2.91027	40	OLD GROWTH FOREST-HIGH
A	2.88161	40	Mossy Forest
A	2.86050	40	OLD GROWTH FOREST-LOW

---------- SLOPE + ASPECT CLASS=15 ----------

Number of observations in by Group = 320

Dependent Variable: LRADAR

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	7	0.5128432	0.0732633	2.29	0.0272
Error	312	9.9656438	0.0319412		
Corrected Total	319	10.4784870			

R-Square	C.V.	Root MSE	LRADAR Mean
0.048942	6.245612	0.1787	2.8615

Source	DF	Type III SS	Mean Square	F Value	Pr > F
GROUP	7	0.5128432	0.0732633	2.29	0.0272

Duncan's Multiple Range Test for variable: LRADAR

Alpha= 0.05 df= 312 MSE= 0.031941

Number of Means	2	3	4	5	6	7	8
Critical Range	.07863	.08278	.08555	.08759	.08919	.09049	.09158

Duncan Grouping	Mean	N	GROUP
A	2.93008	40	Open Land
A	2.91093	40	Grassland
B A	2.86727	40	OLD GROWTH FOREST-HIGH
B A	2.86616	40	Submarginal Forest
B A	2.85038	40	OLD GROWTH FOREST-LOW
B A	2.84505	40	RESIDUAL FOREST
B	2.82051	40	Brushland
B	2.80197	40	Mossy Forest

---------- SLOPE + ASPECT CLASS=16 ----------

Number of observations in by Group = 320

Dependent Variable: LRADAR

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	7	0.8697524	0.1242503	3.54	0.0011
Error	312	10.9581335	0.0351222		
Corrected Total	319	11.8278858			

R-Square	C.V.	Root MSE	LRADAR Mean
0.073534	6.527634	0.1874	2.8710

Source	DF	Type III SS	Mean Square	F Value	Pr > F
GROUP	7	0.8697524	0.1242503	3.54	0.0011

Duncan's Multiple Range Test for variable: LRADAR

Alpha= 0.05 df= 312 MSE= 0.035122

Number of Means	2	3	4	5	6	7	8
Critical Range	.08246	.08681	.08971	.09185	.09353	.09489	.09603

Duncan Grouping	Mean	N	GROUP
A	2.91628	40	RESIDUAL FOREST
A	2.91627	40	OLD GROWTH FOREST-HIGH
A	2.91312	40	Brushland
A	2.90931	40	Grassland
A	2.88789	40	Mossy Forest
B A	2.84813	40	Submarginal Forest
B	2.78931	40	Open Land
B	2.78781	40	OLD GROWTH FOREST-LOW

---------- SLOPE + ASPECT CLASS=17 ----------

Number of observations in by Group = 320

Dependent Variable: LRADAR

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	7	1.0973025	0.1567575	3.28	0.0022
Error	312	14.9191403	0.0478178		
Corrected Total	319	16.0164428			

R-Square	C.V.	Root MSE	LRADAR Mean
0.068511	7.498781	0.2187	2.9161

Source	DF	Type III SS	Mean Square	F Value	Pr > F
GROUP	7	1.0973025	0.1567575	3.28	0.0022

Duncan's Multiple Range Test for variable: LRADAR

Alpha= 0.05 df= 312 MSE= 0.047818

Number of Means	2	3	4	5	6	7	8
Critical Range	.0962	.1013	.1047	.1072	.1091	.1107	.1120

Duncan Grouping	Mean	N	GROUP
A	2.99246	40	Brushland
A	2.97464	40	Grassland
A	2.97411	40	RESIDUAL FOREST
B A	2.93411	40	OLD GROWTH FOREST-HIGH
B A C	2.90413	40	Submarginal Forest
B C	2.86596	40	OLD GROWTH FOREST-LOW
B C	2.86133	40	Open Land
C	2.82215	40	Mossy Forest

---------- SLOPE + ASPECT CLASS=18 ----------

Number of observations in by Group = 320

Dependent Variable: LRADAR

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	7	1.5714741	0.2244963	5.20	0.0001
Error	312	13.4815483	0.0432101		
Corrected Total	319	15.0530224			

R-Square	C.V.	Root MSE	LRADAR Mean
0.104396	7.064816	0.2079	2.9423

Source	DF	Type III SS	Mean Square	F Value	Pr > F
GROUP	7	1.5714741	0.2244963	5.20	0.0001

Duncan's Multiple Range Test for variable: LRADAR

Alpha= 0.05 df= 312 MSE= 0.04321

Number of Means	2	3	4	5	6	7	8
Critical Range	.0915	.0963	.0995	.1019	.1037	.1052	.1065

Duncan Grouping	Mean	N	GROUP
A	3.04479	40	RESIDUAL FOREST
A	3.01549	40	OLD GROWTH FOREST-HIGH
A	3.00608	40	Brushland
B A	2.96711	40	Submarginal Forest
B C	2.89425	40	OLD GROWTH FOREST-LOW
B C	2.88770	40	Mossy Forest
B C	2.87638	40	Grassland
C	2.84687	40	Open Land

---------- SLOPE + ASPECT CLASS=21----------

Number of observations in by Group = 320

Dependent Variable: LRADAR

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	7	1.8318805	0.2616972	5.89	0.0001
Error	312	13.8687427	0.0444511		
Corrected Total	319	15.7006232			

R-Square	C.V.	Root MSE	LRADAR Mean
0.116676	7.011318	0.2108	3.0071

Source	DF	Type III SS	Mean Square	F Value	Pr > F
GROUP	7	1.8318805	0.2616972	5.89	0.0001

Duncan's Multiple Range Test for variable: LRADAR

Alpha= 0.05 df= 312 MSE= 0.044451

Number of Means	2	3	4	5	6	7	8
Critical Range	.0928	.0977	.1009	.1033	.1052	.1067	.1080

Duncan Grouping	Mean	N	GROUP
A	3.13269	40	OLD GROWTH FOREST-HIGH
B A	3.07312	40	Mossy Forest
B A	3.07168	40	Brushland
B C	3.01707	40	Grassland
B C D	2.98670	40	OLD GROWTH FOREST-LOW
C D	2.94759	40	RESIDUAL FOREST
C D	2.91743	40	Submarginal Forest
D	2.91016	40	Open Land

---------- SLOPE + ASPECT CLASS=22 ----------

Number of observations in by Group = 320

Dependent Variable: LRADAR

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	7	1.7153830	0.2450547	6.16	0.0001
Error	312	12.4098413	0.0397751		
Corrected Total	319	14.1252243			

R-Square	C.V.	Root MSE	LRADAR Mean
0.121441	6.756205	0.1994	2.9519

Source	DF	Type III SS	Mean Square	F Value	Pr > F
GROUP	7	1.7153830	0.2450547	6.16	0.0001

Duncan's Multiple Range Test for variable: LRADAR

Alpha= 0.05 df= 312 MSE= 0.039775

Number of Means	2	3	4	5	6	7	8
Critical Range	.0877	.0924	.0955	.0977	.0995	.1010	.1022

Duncan Grouping	Mean	N	GROUP	
A	3.04412	40	Submarginal Forest	
A	3.03220	40	RESIDUAL FOREST	
A	2.97245	40	Mossy Forest	
A	2.97212	40	Grassland	
A	2.96694	40	Brushland	
A	2.95075	40	OLD GROWTH	FOREST-LOW
B	2.86163	40	OLD GROWTH	FOREST-HIGH
B	2.81506	40	Open Land	

---------- SLOPE + ASPECT CLASS=23 ----------

Number of observations in by Group = 320

Dependent Variable: LRADAR

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	7	0.5925443	0.0846492	2.75	0.0088
Error	312	9.6113360	0.0308056		
Corrected Total	319	10.2038803			

R-Square	C.V.	Root MSE	LRADAR Mean
0.058070	6.073080	0.1755	2.8901

Source	DF	Type III SS	Mean Square	F Value	Pr > F
GROUP	7	0.5925443	0.0846492	2.75	0.0088

Duncan's Multiple Range Test for variable: LRADAR

Alpha= 0.05 df= 312 MSE= 0.030806

Number of Means	2	3	4	5	6	7	8
Critical Range	.07722	.08130	.08402	.08602	.08759	.08887	.08993

Duncan Grouping	Mean	N	GROUP	
A	2.96694	40	Grassland	
B A	2.92105	40	Brushland	
B A	2.91067	40	OLD GROWTH	FOREST-HIGH
B A	2.90343	40	Submarginal Forest	
B C	2.87492	40	OLD GROWTH	FOREST-LOW
B C	2.87301	40	Mossy Forest	
B C	2.85519	40	RESIDUAL FOREST	
C	2.81520	40	Open Land	

---------- SLOPE + ASPECT CLASS=24 ----------

Number of observations in by Group = 320

Dependent Variable: LRADAR

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	7	0.9337491	0.1333927	3.10	0.0036
Error	312	13.4382540	0.0430713		
Corrected Total	319	14.3720031			

R-Square	C.V.	Root MSE	LRADAR Mean
0.064970	7.190620	0.2075	2.8862

Source	DF	Type III SS	Mean Square	F Value	Pr > F
GROUP	7	0.9337491	0.1333927	3.10	0.0036

Duncan's Multiple Range Test for variable: LRADAR

Alpha= 0.05 df= 312 MSE= 0.043071

Number of Means	2	3	4	5	6	7	8
Critical Range	.0913	.0961	.0993	.1017	.1036	.1051	.1063

Duncan Grouping	Mean	N	GROUP
A	2.97264	40	Open Land
A	2.92286	40	Brushland
A	2.90190	40	Submarginal Forest
A	2.90153	40	RESIDUAL FOREST
A	2.87585	40	Mossy Forest
A	2.87545	40	OLD GROWTH FOREST-LOW
A	2.86966	40	Grassland
B	2.76979	40	OLD GROWTH FOREST-HIGH

---------- SLOPE + ASPECT CLASS=25 ----------

Number of observations in by Group = 320

Dependent Variable: LRADAR

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	7	0.4153397	0.0593342	1.72	0.1039
Error	312	10.7693878	0.0345173		
Corrected Total	319	11.1847275			

R-Square	C.V.	Root MSE	LRADAR Mean
0.037135	6.485660	0.1858	2.8646

Source	DF	Type III SS	Mean Square	F Value	Pr > F
GROUP	7	0.4153397	0.0593342	1.72	0.1039

Duncan's Multiple Range Test for variable: LRADAR

Alpha= 0.05 df= 312 MSE= 0.034517

Number of Means	2	3	4	5	6	7	8
Critical Range	.08174	.08605	.08893	.09106	.09272	.09407	.09520

Duncan Grouping		Mean	N	GROUP
	A	2.89867	40	Open Land
	A	2.89063	40	Brushland
	A	2.88982	40	OLD GROWTH FOREST-LOW
	A	2.88966	40	Mossy Forest
B	A	2.87095	40	RESIDUAL FOREST
B	A	2.85886	40	Grassland
B	A	2.83199	40	Submarginal Forest
B		2.78622	40	OLD GROWTH FOREST-HIGH

---------- SLOPE + ASPECT CLASS=26 ----------

Number of observations in by Group = 320

Dependent Variable: LRADAR

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	7	0.9195583	0.1313655	2.56	0.0141
Error	312	16.0160567	0.0513335		
Corrected Total	319	16.9356150			

R-Square	C.V.	Root MSE	LRADAR Mean
0.054297	7.840215	0.2266	2.8898

Source	DF	Type III SS	Mean Square	F Value	Pr > F
GROUP	7	0.9195583	0.1313655	2.56	0.0141

Duncan's Multiple Range Test for variable: LRADAR

Alpha= 0.05 df= 312 MSE= 0.051334

Number of Means	2	3	4	5	6	7	8
Critical Range	.0997	.1049	.1085	.1110	.1131	.1147	.1161

Duncan Grouping	Mean	N	GROUP
A	2.96866	40	RESIDUAL FOREST
B A	2.95584	40	Grassland
B A C	2.92249	40	OLD GROWTH FOREST-LOW
B A C	2.90694	40	Mossy Forest
B A C	2.86153	40	OLD GROWTH FOREST-HIGH
B C	2.85478	40	Open Land
C	2.83863	40	Brushland
C	2.80978	40	Submarginal Forest

---------- SLOPE + ASPECT CLASS=27 ----------

Number of observations in by Group = 320

Dependent Variable: LRADAR

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	7	0.7572849	0.1081836	2.31	0.0262
Error	312	14.6183465	0.0468537		
Corrected Total	319	15.3756315			

R-Square	C.V.	Root MSE	LRADAR Mean
0.049252	7.315424	0.2165	2.9589

Source	DF	Type III SS	Mean Square	F Value	Pr > F
GROUP	7	0.7572849	0.1081836	2.31	0.0262

Duncan's Multiple Range Test for variable: LRADAR

Alpha= 0.05 df= 312 MSE= 0.046854

Number of Means	2	3	4	5	6	7	8
Critical Range	.0952	.1003	.1036	.1061	.1080	.1096	.1109

Duncan Grouping	Mean	N	GROUP
A	3.04930	40	Grassland
B A	2.99931	40	OLD GROWTH FOREST-HIGH
B A C	2.98160	40	Submarginal Forest
B A C	2.95162	40	Mossy Forest
B A C	2.95056	40	Brushland
B C	2.93492	40	RESIDUAL FOREST
B C	2.92883	40	OLD GROWTH FOREST-LOW
C	2.87518	40	Open Land

---------- SLOPE + ASPECT CLASS=28 ----------

Number of observations in by Group = 320

Dependent Variable: LRADAR

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	7	2.6264478	0.3752068	8.62	0.0001
Error	312	13.5771621	0.0435165		
Corrected Total	319	16.2036099			

R-Square	C.V.	Root MSE	LRADAR Mean
0.162090	6.911172	0.2086	3.0184

Source	DF	Type III SS	Mean Square	F Value	Pr > F
GROUP	7	2.6264478	0.3752068	8.62	0.0001

Duncan's Multiple Range Test for variable: LRADAR

Alpha= 0.05 df= 312 MSE= 0.043517

Number of Means	2	3	4	5	6	7	8
Critical Range	.0918	.0966	.0999	.1022	.1041	.1056	.1069

Duncan Grouping	Mean	N	GROUP
A	3.16441	40	Submarginal Forest
B A	3.07427	40	Grassland
B A	3.06989	40	OLD GROWTH FOREST-HIGH
B	3.05765	40	RESIDUAL FOREST
B	3.02022	40	Brushland
B	2.99325	40	Open Land
C	2.89128	40	Mossy Forest
C	2.87616	40	OLD GROWTH FOREST-LOW

---------- SLOPE + ASPECT CLASS=31 ----------

Number of observations in by Group = 320

Dependent Variable: LRADAR

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	7	2.7124446	0.3874921	8.82	0.0001
Error	312	13.7005473	0.0439120		
Corrected Total	319	16.4129920			

R-Square	C.V.	Root MSE	LRADAR Mean
0.165262	6.835097	0.2096	3.0658

Source	DF	Type III SS	Mean Square	F Value	Pr > F
GROUP	7	2.7124446	0.3874921	8.82	0.0001

Duncan's Multiple Range Test for variable: LRADAR

Alpha= 0.05 df= 312 MSE= 0.043912

Number of Means	2	3	4	5	6	7	8
Critical Range	.0922	.0971	.1003	.1027	.1046	.1061	.1074

Duncan Grouping	Mean	N	GROUP
A	3.23359	40	Grassland
B A	3.16759	40	OLD GROWTH FOREST-HIGH
B C	3.10100	40	Submarginal Forest
B C D	3.07888	40	Brushland
E C D	3.02209	40	Open Land
E D	2.99529	40	RESIDUAL FOREST
E	2.97634	40	Mossy Forest
E	2.95179	40	OLD GROWTH FOREST-LOW

---------- SLOPE + ASPECT CLASS=32 ----------

Number of observations in by Group = 320

Dependent Variable: LRADAR

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	7	1.3950570	0.1992939	6.11	0.0001
Error	312	10.1817467	0.0326338		
Corrected Total	319	11.5768037			

R-Square	C.V.	Root MSE	LRADAR Mean
0.120505	6.005923	0.1806	3.0078

Source	DF	Type III SS	Mean Square	F Value	Pr > F
GROUP	7	1.3950570	0.1992939	6.11	0.0001

Duncan's Multiple Range Test for variable: LRADAR

Alpha= 0.05 df= 312 MSE= 0.032634

Number of Means	2	3	4	5	6	7	8
Critical Range	.07948	.08367	.08647	.08854	.09015	.09147	.09256

Duncan Grouping	Mean	N	GROUP
A	3.06474	40	Brushland
A	3.06255	40	Grassland
A	3.04430	40	Mossy Forest
A	3.04352	40	OLD GROWTH FOREST-HIGH
A	3.03395	40	RESIDUAL FOREST
B A	3.00823	40	Submarginal Forest
B	2.94301	40	OLD GROWTH FOREST-LOW
C	2.86238	40	Open Land

---------- SLOPE + ASPECT CLASS=33 ----------

Number of observations in by Group = 320

Dependent Variable: LRADAR

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	7	1.2795954	0.1827993	4.97	0.0001
Error	312	11.4767994	0.0367846		
Corrected Total	319	12.7563948			

R-Square	C.V.	Root MSE	LRADAR Mean
0.100310	6.612921	0.1918	2.9003

Source	DF	Type III SS	Mean Square	F Value	Pr > F
GROUP	7	1.2795954	0.1827993	4.97	0.0001

Duncan's Multiple Range Test for variable: LRADAR

Alpha= 0.05 df= 312 MSE= 0.036785

Number of Means	2	3	4	5	6	7	8
Critical Range	.08439	.08884	.09181	.09400	.09571	.09711	.09827

Duncan Grouping	Mean	N	GROUP
A	2.98369	40	Grassland
A	2.95768	40	Mossy Forest
B A	2.93170	40	RESIDUAL FOREST
B A	2.92967	40	Brushland
B A	2.92703	40	Submarginal Forest
B C	2.85058	40	OLD GROWTH FOREST-HIGH
C	2.83011	40	OLD GROWTH FOREST-LOW
C	2.79176	40	Open Land

---------- SLOPE + ASPECT CLASS=34 ----------

Number of observations in by Group = 320

Dependent Variable: LRADAR

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	7	0.7073097	0.1010442	3.23	0.0026
Error	312	9.7700007	0.0313141		
Corrected Total	319	10.4773104			

R-Square	C.V.	Root MSE	LRADAR Mean
0.067509	6.283734	0.1770	2.8161

Source	DF	Type III SS	Mean Square	F Value	Pr > F
GROUP	7	0.7073097	0.1010442	3.23	0.0026

Duncan's Multiple Range Test for variable: LRADAR

Alpha= 0.05 df= 312 MSE= 0.031314

Number of Means	2	3	4	5	6	7	8
Critical Range	.07786	.08196	.08471	.08673	.08831	.08960	.09067

Duncan Grouping	Mean	N	GROUP
A	2.90344	40	Brushland
B A	2.86291	40	OLD GROWTH FOREST-HIGH
B A C	2.82660	40	Submarginal Forest
B C	2.81296	40	OLD GROWTH FOREST-LOW
B C	2.81048	40	Mossy Forest
B C	2.79056	40	RESIDUAL FOREST
B C	2.78332	40	Open Land
C	2.73874	40	Grassland

---------- SLOPE + ASPECT CLASS=35 ----------

Number of observations in by Group = 320

Dependent Variable: LRADAR

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	7	0.7626624	0.1089518	3.55	0.0011
Error	312	9.5828424	0.0307142		
Corrected Total	319	10.3455048			

R-Square	C.V.	Root MSE	LRADAR Mean
0.073719	6.107088	0.1753	2.8697

Source	DF	Type III SS	Mean Square	F Value	Pr > F
GROUP	7	0.7626624	0.1089518	3.55	0.0011

Duncan's Multiple Range Test for variable: LRADAR

Alpha= 0.05 df= 312 MSE= 0.030714

Number of Means	2	3	4	5	6	7	8
Critical Range	.07711	.08118	.08389	.08589	.08746	.08874	.08980

Duncan Grouping	Mean	N	GROUP
A	2.97074	40	OLD GROWTH FOREST-HIGH
B A	2.89731	40	Submarginal Forest
B C	2.88745	40	Brushland
B C	2.87694	40	OLD GROWTH FOREST-LOW
B C	2.85450	40	Open Land
B C	2.84795	40	Grassland
B C	2.82159	40	Mossy Forest
C	2.80108	40	RESIDUAL FOREST

---------- SLOPE + ASPECT CLASS=36 ----------

Number of observations in by Group = 320

Dependent Variable: LRADAR

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	7	0.6264728	0.0894961	1.82	0.0820
Error	312	15.3037962	0.0490506		
Corrected Total	319	15.9302691			

R-Square	C.V.	Root MSE	LRADAR Mean
0.039326	7.603841	0.2215	2.9127

Source	DF	Type III SS	Mean Square	F Value	Pr > F
GROUP	7	0.6264728	0.0894961	1.82	0.0820

Duncan's Multiple Range Test for variable: LRADAR

Alpha= 0.05 df= 312 MSE= 0.049051

Number of Means	2	3	4	5	6	7	8
Critical Range	.0974	.1026	.1060	.1085	.1105	.1121	.1135

Duncan Grouping	Mean	N	GROUP
A	2.98989	40	OLD GROWTH FOREST-HIGH
B A	2.94577	40	Mossy Forest
B A	2.94561	40	Brushland
B A	2.92155	40	RESIDUAL FOREST
B A	2.89646	40	OLD GROWTH FOREST-LOW
B A	2.89325	40	Open Land
B	2.85474	40	Grassland
B	2.85398	40	Submarginal Forest

---------- SLOPE + ASPECT CLASS=37 ----------

Number of observations in by Group = 320

Dependent Variable: LRADAR

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	7	0.5843283	0.0834755	1.82	0.0838
Error	312	14.3485221	0.0459889		
Corrected Total	319	14.9328504			

R-Square	C.V.	Root MSE	LRADAR Mean
0.039130	7.326267	0.2145	2.9271

Source	DF	Type III SS	Mean Square	F Value	Pr > F
GROUP	7	0.5843283	0.0834755	1.82	0.0838

Duncan's Multiple Range Test for variable: LRADAR

Alpha= 0.05 df= 312 MSE= 0.045989

Number of Means	2	3	4	5	6	7	8
Critical Range	.0944	.0993	.1027	.1051	.1070	.1086	.1099

Duncan Grouping	Mean	N	GROUP
A	2.99808	40	OLD GROWTH FOREST-HIGH
B A	2.98453	40	RESIDUAL FOREST
B A	2.94417	40	Grassland
B A	2.92941	40	Brushland
B A	2.90937	40	Submarginal Forest
B	2.88924	40	Mossy Forest
B	2.88291	40	Open Land
B	2.87940	40	OLD GROWTH FOREST-LOW

---------- SLOPE + ASPECT CLASS=38 ----------

Number of observations in by Group = 320

Dependent Variable: LRADAR

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	7	3.8150480	0.5450069	11.59	0.0001
Error	312	14.6676404	0.0470117		
Corrected Total	319	18.4826884			

R-Square	C.V.	Root MSE	LRADAR Mean
0.206412	7.056178	0.2168	3.0728

Source	DF	Type III SS	Mean Square	F Value	Pr > F
GROUP	7	3.8150480	0.5450069	11.59	0.0001

Duncan's Multiple Range Test for variable: LRADAR

Alpha= 0.05 df= 312 MSE= 0.047012

Number of Means	2	3	4	5	6	7	8
Critical Range	.0954	.1004	.1038	.1063	.1082	.1098	.1111

Duncan Grouping			Mean	N	GROUP
	A		3.22949	40	OLD GROWTH FOREST-HIGH
	A		3.18601	40	Grassland
	A		3.18150	40	Submarginal Forest
	B		3.08297	40	RESIDUAL FOREST
C	B		3.04023	40	Open Land
C	B	D	2.99156	40	Mossy Forest
C		D	2.95277	40	Brushland
		D	2.91781	40	OLD GROWTH FOREST-LOW

---------- SLOPE + ASPECT CLASS=41 ----------

Number of observations in by Group = 320

Dependent Variable: LRADAR

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	7	4.3626665	0.6232381	13.37	0.0001
Error	312	14.5454622	0.0466201		
Corrected Total	319	18.9081286			

R-Square	C.V.	Root MSE	LRADAR Mean
0.230730	7.153151	0.2159	3.0185

Source	DF	Type III SS	Mean Square	F Value	Pr > F
GROUP	7	4.3626665	0.6232381	13.37	0.0001

Duncan's Multiple Range Test for variable: LRADAR

Alpha= 0.05 df= 312 MSE= 0.04662

Number of Means	2	3	4	5	6	7	8
Critical Range	.0950	.1000	.1034	.1058	.1078	.1093	.1106

Duncan Grouping			Mean	N	GROUP
	A		3.16039	40	OLD GROWTH FOREST-HIGH
B	A		3.13726	40	Brushland
B	A		3.12094	40	Submarginal Forest
B	A		3.06397	40	OLD GROWTH FOREST-LOW
B			3.03888	40	RESIDUAL FOREST
	C		2.88832	40	Grassland
	C		2.88009	40	Mossy Forest
	C		2.85804	40	Open Land

---------- SLOPE + ASPECT CLASS=42 ----------

Number of observations in by Group = 320

Dependent Variable: LRADAR

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	7	2.5969381	0.3709912	8.38	0.0001
Error	312	13.8080760	0.0442567		
Corrected Total	319	16.4050142			

R-Square	C.V.	Root MSE	LRADAR Mean
0.158301	7.027996	0.2104	2.9934

Source	DF	Type III SS	Mean Square	F Value	Pr > F
GROUP	7	2.5969381	0.3709912	8.38	0.0001

Duncan's Multiple Range Test for variable: LRADAR

Alpha= 0.05 df= 312 MSE= 0.044257

Number of Means	2	3	4	5	6	7	8
Critical Range	.0926	.0974	.1007	.1031	.1050	.1065	.1078

Duncan Grouping		Mean	N	GROUP
	A	3.11050	40	Grassland
	A	3.08213	40	Submarginal Forest
	A	3.07436	40	Mossy Forest
B	A	3.03101	40	Brushland
B	C	2.96826	40	RESIDUAL FOREST
D	C	2.93192	40	OLD GROWTH FOREST-LOW
D	C	2.91033	40	OLD GROWTH FOREST-HIGH
D		2.83830	40	Open Land

---------- SLOPE + ASPECT CLASS=43 ----------

Number of observations in by Group = 216

Dependent Variable: LRADAR

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	7	31.510449	4.501493	20.45	0.0001
Error	208	45.777560	0.220084		
Corrected Total	215	77.288009			

R-Square	C.V.	Root MSE	LRADAR Mean
0.407702	17.08453	0.4691	2.7459

Source	DF	Type III SS	Mean Square	F Value	Pr > F
GROUP	7	31.510449	4.501493	20.45	0.0001

Duncan's Multiple Range Test for variable: LRADAR

Alpha= 0.05 df= 208 MSE= 0.220084

Number of Means	2	3	4	5	6	7	8
Critical Range	.2517	.2650	.2738	.2803	.2854	.2895	.2930

Duncan Grouping	Mean	N	GROUP
A	2.9747	27	Mossy Forest
A	2.9335	27	Grassland
A	2.9125	27	OLD GROWTH FOREST-HIGH
A	2.8962	27	Submarginal Forest
A	2.8807	27	Brushland
A	2.8749	27	RESIDUAL FOREST
A	2.7463	27	OLD GROWTH FOREST-LOW
B	1.7487	27	Open Land

---------- SLOPE + ASPECT CLASS=44 ----------

Number of observations in by Group = 312

Dependent Variable: LRADAR

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	7	1.4970124	0.2138589	5.49	0.0001
Error	304	11.8359951	0.0389342		
Corrected Total	311	13.3330075			

R-Square	C.V.	Root MSE	LRADAR Mean
0.112279	6.970707	0.1973	2.8307

Source	DF	Type III SS	Mean Square	F Value	Pr > F
GROUP	7	1.4970124	0.2138589	5.49	0.0001

Duncan's Multiple Range Test for variable: LRADAR

Alpha= 0.05 df= 304 MSE= 0.038934

Number of Means	2	3	4	5	6	7	8
Critical Range	.0879	.0926	.0957	.0979	.0997	.1012	.1024

Duncan Grouping	Mean	N	GROUP
A	2.99774	39	Grassland
B	2.85017	39	OLD GROWTH FOREST-HIGH
B	2.83082	39	Brushland
B	2.82214	39	Mossy Forest
B	2.82052	39	Submarginal Forest
B	2.79149	39	Open Land
B	2.77232	39	OLD GROWTH FOREST-LOW
B	2.76013	39	RESIDUAL FOREST

---------- SLOPE + ASPECT CLASS=45 ----------

Number of observations in by Group = 320

Dependent Variable: LRADAR

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	7	3.2475588	0.4639370	11.96	0.0001
Error	312	12.0991789	0.0387794		
Corrected Total	319	15.3467377			

R-Square	C.V.	Root MSE	LRADAR Mean
0.211612	6.944004	0.1969	2.8359

Source	DF	Type III SS	Mean Square	F Value	Pr > F
GROUP	7	3.2475588	0.4639370	11.96	0.0001

Duncan's Multiple Range Test for variable: LRADAR

Alpha= 0.05 df= 312 MSE= 0.038779

Number of Means	2	3	4	5	6	7	8
Critical Range	.0866	.0912	.0943	.0965	.0983	.0997	.1009

Duncan Grouping	Mean	N	GROUP
A	3.06797	40	Grassland
B	2.90546	40	Brushland
C B	2.83939	40	Submarginal Forest
C D	2.81393	40	OLD GROWTH FOREST-HIGH
C D	2.78936	40	OLD GROWTH FOREST-LOW
C D	2.77359	40	RESIDUAL FOREST
C D	2.76820	40	Open Land
D	2.72928	40	Mossy Forest

---------- SLOPE + ASPECT CLASS=46 ----------

Number of observations in by Group = 320

Dependent Variable: LRADAR

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	7	0.6563528	0.0937647	2.46	0.0183
Error	312	11.9139572	0.0381858		
Corrected Total	319	12.5703100			

R-Square	C.V.	Root MSE	LRADAR Mean
0.052215	6.890515	0.1954	2.8360

Source	DF	Type III SS	Mean Square	F Value	Pr > F
GROUP	7	0.6563528	0.0937647	2.46	0.0183

Duncan's Multiple Range Test for variable: LRADAR

Alpha= 0.05 df= 312 MSE= 0.038186

Number of Means	2	3	4	5	6	7	8
Critical Range	.0860	.0905	.0935	.0958	.0975	.0989	.1001

Duncan Grouping	Mean	N	GROUP
A	2.88655	40	Grassland
A	2.87025	40	OLD GROWTH FOREST-HIGH
A	2.86167	40	Brushland
A	2.85113	40	RESIDUAL FOREST
A	2.83624	40	Mossy Forest
A	2.82803	40	OLD GROWTH FOREST-LOW
A	2.82555	40	Submarginal Forest
B	2.72821	40	Open Land

---------- SLOPE + ASPECT CLASS=47 ----------

Number of observations in by Group = 320

Dependent Variable: LRADAR

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	7	2.6852272	0.3836039	9.81	0.0001
Error	312	12.2049892	0.0391186		
Corrected Total	319	14.8902164			

R-Square	C.V.	Root MSE	LRADAR Mean
0.180335	6.684785	0.1978	2.9587

Source	DF	Type III SS	Mean Square	F Value	Pr > F
GROUP	7	2.6852272	0.3836039	9.81	0.0001

Duncan's Multiple Range Test for variable: LRADAR

Alpha= 0.05 df= 312 MSE= 0.039119

Number of Means	2	3	4	5	6	7	8
Critical Range	.0870	.0916	.0947	.0969	.0987	.1001	.1013

Duncan Grouping	Mean	N	GROUP
A	3.05485	40	RESIDUAL FOREST
A	3.04346	40	Open Land
B A	3.03018	40	Mossy Forest
B A	3.03012	40	Brushland
B C	2.94021	40	OLD GROWTH FOREST-HIGH
C	2.90013	40	OLD GROWTH FOREST-LOW
C	2.89162	40	Submarginal Forest
D	2.77920	40	Grassland

---------- SLOPE + ASPECT CLASS=48 ----------

Number of observations in by Group = 320

Dependent Variable: LRADAR

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	7	3.9007898	0.5572557	10.67	0.0001
Error	312	16.2896986	0.0522106		
Corrected Total	319	20.1904884			

R-Square	C.V.	Root MSE	LRADAR Mean
0.193199	7.521263	0.2285	3.0380

Source	DF	Type III SS	Mean Square	F Value	Pr > F
GROUP	7	3.9007898	0.5572557	10.67	0.0001

Duncan's Multiple Range Test for variable: LRADAR

Alpha= 0.05 df= 312 MSE= 0.052211

Number of Means	2	3	4	5	6	7	8
Critical Range	.1005	.1058	.1094	.1120	.1140	.1157	.1171

Duncan Grouping		Mean	N	GROUP
	A	3.20516	40	Open Land
B	A	3.12504	40	OLD GROWTH FOREST-HIGH
B	A	3.11526	40	Brushland
B	C	3.05903	40	RESIDUAL FOREST
B	C	3.01693	40	OLD GROWTH FOREST-LOW
	C	3.00408	40	Grassland
	C	2.95907	40	Mossy Forest
	D	2.81945	40	Submarginal Forest

---------- SLOPE + ASPECT CLASS=51 ----------

Number of observations in by Group = 320

Dependent Variable: LRADAR

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	7	4.7383351	0.6769050	12.01	0.0001
Error	312	17.5886538	0.0563739		
Corrected Total	319	22.3269889			

R-Square	C.V.	Root MSE	LRADAR Mean
0.212225	7.669410	0.2374	3.0958

Source	DF	Type III SS	Mean Square	F Value	Pr > F
GROUP	7	4.7383351	0.6769050	12.01	0.0001

Duncan's Multiple Range Test for variable: LRADAR

Alpha= 0.05 df= 312 MSE= 0.056374

Number of Means	2	3	4	5	6	7	8
Critical Range	.1045	.1100	.1137	.1164	.1185	.1202	.1217

Duncan Grouping			Mean	N	GROUP
	A		3.29368	40	Open Land
B	A		3.21335	40	Brushland
B	C		3.16736	40	OLD GROWTH FOREST-HIGH
B	C	D	3.12006	40	RESIDUAL FOREST
	C	D	3.08263	40	Grassland
	E	D	3.03071	40	Submarginal Forest
	E		2.93078	40	OLD GROWTH FOREST-LOW
	E		2.92806	40	Mossy Forest

---------- SLOPE + ASPECT CLASS=52 ----------

Number of observations in by Group = 320

Dependent Variable: LRADAR

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	7	2.7304508	0.3900644	7.87	0.0001
Error	312	15.4709393	0.0495863		
Corrected Total	319	18.2013901			

R-Square	C.V.	Root MSE	LRADAR Mean
0.150013	7.546389	0.2227	2.9508

Source	DF	Type III SS	Mean Square	F Value	Pr > F
GROUP	7	2.7304508	0.3900644	7.87	0.0001

Duncan's Multiple Range Test for variable: LRADAR

Alpha= 0.05 df= 312 MSE= 0.049586

Number of Means	2	3	4	5	6	7	8
Critical Range	.0980	.1031	.1066	.1091	.1111	.1127	.1141

Duncan Grouping	Mean	N	GROUP
A	3.07980	40	Grassland
A	3.06230	40	Submarginal Forest
A	3.06076	40	Open Land
B	2.90866	40	OLD GROWTH FOREST-LOW
B	2.89809	40	RESIDUAL FOREST
B	2.88352	40	Mossy Forest
B	2.86896	40	OLD GROWTH FOREST-HIGH
B	2.84441	40	Brushland

---------- SLOPE + ASPECT CLASS=53 ----------

Number of observations in by Group = 160

Dependent Variable: LRADAR

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	7	84.721814	12.103116	408.29	0.0001
Error	152	4.505838	0.029644		
Corrected Total	159	89.227652			

R-Square	C.V.	Root MSE	LRADAR Mean
0.949502	6.566757	0.1722	2.6219

Source	DF	Type III SS	Mean Square	F Value	Pr > F
GROUP	7	84.721814	12.103116	408.29	0.0001

Duncan's Multiple Range Test for variable: LRADAR

Alpha= 0.05 df= 152 MSE= 0.029644

Number of Means	2	3	4	5	6	7	8
Critical Range	.1076	.1132	.1170	.1198	.1219	.1237	.1251

Duncan Grouping		Mean	N	GROUP
	A	2.97689	20	Grassland
B	A	2.90520	20	OLD GROWTH FOREST-LOW
B	A	2.90442	20	RESIDUAL FOREST
B	A	2.90042	20	Submarginal Forest
B	A	2.87187	20	OLD GROWTH FOREST-HIGH
B	A	2.86706	20	Mossy Forest
B		2.85032	20	Brushland
	C	0.69897	20	Open Land

---------- SLOPE + ASPECT CLASS=54 ----------

Number of observations in by Group = 272

Dependent Variable: LRADAR

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	7	5.3468278	0.7638325	5.92	0.0001
Error	264	34.0404352	0.1289410		
Corrected Total	271	39.3872630			

R-Square	C.V.	Root MSE	LRADAR Mean
0.135750	13.05845	0.3591	2.7498

Source	DF	Type III SS	Mean Square	F Value	Pr > F
GROUP	7	5.3468278	0.7638325	5.92	0.0001

Duncan's Multiple Range Test for variable: LRADAR

Alpha= 0.05 df= 264 MSE= 0.128941

Number of Means	2	3	4	5	6	7	8
Critical Range	.1715	.1805	.1866	.1910	.1945	.1973	.1997

Duncan Grouping	Mean	N	GROUP
A	2.86929	34	Grassland
A	2.86556	34	Mossy Forest
A	2.80265	34	Brushland
A	2.78432	34	OLD GROWTH FOREST-HIGH
A	2.77884	34	Submarginal Forest
A	2.76920	34	RESIDUAL FOREST
A	2.73106	34	OLD GROWTH FOREST-LOW
B	2.39763	34	Open Land

---------- SLOPE + ASPECT CLASS=55 ----------

Number of observations in by Group = 312

Dependent Variable: LRADAR

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	7	6.6832267	0.9547467	26.27	0.0001
Error	304	11.0483146	0.0363431		
Corrected Total	311	17.7315413			

R-Square	C.V.	Root MSE	LRADAR Mean
0.376912	6.778049	0.1906	2.8126

Source	DF	Type III SS	Mean Square	F Value	Pr > F
GROUP	7	6.6832267	0.9547467	26.27	0.0001

Duncan's Multiple Range Test for variable: LRADAR

Alpha= 0.05 df= 304 MSE= 0.036343

Number of Means	2	3	4	5	6	7	8
Critical Range	.08496	.08943	.09243	.09463	.09636	.09776	.09893

Duncan Grouping	Mean	N	GROUP
A	3.16060	39	Grassland
B	2.90083	39	Submarginal Forest
C	2.78835	39	Mossy Forest
C	2.78095	39	OLD GROWTH FOREST-HIGH
C	2.75663	39	OLD GROWTH FOREST-LOW
D C	2.72985	39	RESIDUAL FOREST
D C	2.72089	39	Open Land
D	2.66262	39	Brushland

---------- SLOPE + ASPECT CLASS=56 ----------

Number of observations in by Group = 320

Dependent Variable: LRADAR

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	7	1.2284096	0.1754871	2.92	0.0057
Error	312	18.7442458	0.0600777		
Corrected Total	319	19.9726554			

R-Square	C.V.	Root MSE	LRADAR Mean
0.061505	8.515818	0.2451	2.8783

Source	DF	Type III SS	Mean Square	F Value	Pr > F
GROUP	7	1.2284096	0.1754871	2.92	0.0057

Duncan's Multiple Range Test for variable: LRADAR

Alpha= 0.05 df= 312 MSE= 0.060078

Number of Means	2	3	4	5	6	7	8
Critical Range	.1078	.1135	.1173	.1201	.1223	.1241	.1256

Duncan Grouping	Mean	N	GROUP
A	2.94576	40	Grassland
A	2.93730	40	Submarginal Forest
A	2.93166	40	OLD GROWTH FOREST-LOW
A	2.88635	40	Mossy Forest
A	2.86894	40	RESIDUAL FOREST
A	2.86754	40	Brushland
B A	2.84643	40	OLD GROWTH FOREST-HIGH
B	2.74211	40	Open Land

---------- SLOPE + ASPECT CLASS=57 ----------

Number of observations in by Group = 296

Dependent Variable: LRADAR

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	7	4.2153601	0.6021943	6.53	0.0001
Error	288	26.5708777	0.0922600		
Corrected Total	295	30.7862378			

R-Square	C.V.	Root MSE	LRADAR Mean
0.136924	10.40515	0.3037	2.9192

Source	DF	Type III SS	Mean Square	F Value	Pr > F
GROUP	7	4.2153601	0.6021943	6.53	0.0001

Duncan's Multiple Range Test for variable: LRADAR

Alpha= 0.05 df= 288 MSE= 0.09226

Number of Means	2	3	4	5	6	7	8
Critical Range	.1390	.1463	.1512	.1548	.1576	.1599	.1619

Duncan Grouping	Mean	N	GROUP
A	3.06465	37	RESIDUAL FOREST
A	3.02479	37	Brushland
B A	2.98437	37	OLD GROWTH FOREST-HIGH
B A	2.98401	37	Mossy Forest
B A C	2.95576	37	Submarginal Forest
B C	2.84151	37	OLD GROWTH FOREST-LOW
D C	2.81211	37	Grassland
D	2.68611	37	Open Land

---------- SLOPE + ASPECT CLASS=58 ----------

Number of observations in by Group = 312

Dependent Variable: LRADAR

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	7	7.4338322	1.0619760	19.65	0.0001
Error	304	16.4270247	0.0540363		
Corrected Total	311	23.8608569			

R-Square	C.V.	Root MSE	LRADAR Mean
0.311549	7.630579	0.2325	3.0464

Source	DF	Type III SS	Mean Square	F Value	Pr > F
GROUP	7	7.4338322	1.0619760	19.65	0.0001

Duncan's Multiple Range Test for variable: LRADAR

Alpha= 0.05 df= 304 MSE= 0.054036

Number of Means	2	3	4	5	6	7	8
Critical Range	.1036	.1091	.1127	.1154	.1175	.1192	.1206

Duncan Grouping		Mean	N	GROUP
	A	3.19998	39	Submarginal Forest
	A	3.18642	39	RESIDUAL FOREST
	A	3.18061	39	Open Land
B	A	3.14024	39	OLD GROWTH FOREST-HIGH
B	C	3.05368	39	Brushland
D	C	2.95142	39	OLD GROWTH FOREST-LOW
D		2.92241	39	Mossy Forest
	E	2.73632	39	Grassland

---------- SLOPE + ASPECT CLASS=61 ----------

Number of observations in by Group = 320

Dependent Variable: LRADAR

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	7	12.037040	1.719577	36.01	0.0001
Error	312	14.897678	0.047749		
Corrected Total	319	26.934718			

R-Square	C.V.	Root MSE	LRADAR Mean
0.446897	7.229996	0.2185	3.0223

Source	DF	Type III SS	Mean Square	F Value	Pr > F
GROUP	7	12.037040	1.719577	36.01	0.0001

Duncan's Multiple Range Test for variable: LRADAR

Alpha= 0.05 df= 312 MSE= 0.047749

Number of Means	2	3	4	5	6	7	8
Critical Range	.0961	.1012	.1046	.1071	.1091	.1106	.1120

Duncan Grouping		Mean	N	GROUP
	A	3.30603	40	Open Land
B	A	3.21196	40	Brushland
B		3.18169	40	RESIDUAL FOREST
	C	3.07327	40	Submarginal Forest
D	C	2.97764	40	Mossy Forest
D		2.92026	40	OLD GROWTH FOREST-LOW
	E	2.75746	40	Grassland
	E	2.75046	40	OLD GROWTH FOREST-HIGH

---------- SLOPE + ASPECT CLASS=62 ----------

Number of observations in by Group = 192

Dependent Variable: LRADAR

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	7	50.486489	7.212356	41.25	0.0001
Error	184	32.173122	0.174854		
Corrected Total	191	82.659611			

R-Square	C.V.	Root MSE	LRADAR Mean
0.610776	15.23250	0.4182	2.7452

Source	DF	Type III SS	Mean Square	F Value	Pr > F
GROUP	7	50.486489	7.212356	41.25	0.0001

Duncan's Multiple Range Test for variable: LRADAR

Alpha= 0.05 df= 184 MSE= 0.174854

Number of Means	2	3	4	5	6	7	8
Critical Range	.2382	.2507	.2590	.2652	.2700	.2739	.2771

Duncan Grouping	Mean	N	GROUP
A	3.0701	24	Submarginal Forest
B A	3.0298	24	Brushland
B A	2.9756	24	Mossy Forest
B A	2.9323	24	Grassland
B A	2.9188	24	RESIDUAL FOREST
B A	2.8626	24	OLD GROWTH FOREST-LOW
B	2.7628	24	OLD GROWTH FOREST-HIGH
C	1.4093	24	Open Land

---------- SLOPE + ASPECT CLASS=63 ----------

Number of observations in by Group = 160

Dependent Variable: LRADAR

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	7	82.222107	11.746015	295.78	0.0001
Error	152	6.036295	0.039712		
Corrected Total	159	88.258402			

R-Square	C.V.	Root MSE	LRADAR Mean
0.931607	7.515811	0.1993	2.6515

Source	DF	Type III SS	Mean Square	F Value	Pr > F
GROUP	7	82.222107	11.746015	295.78	0.0001

Duncan's Multiple Range Test for variable: LRADAR

Alpha= 0.05 df= 152 MSE= 0.039712

Number of Means	2	3	4	5	6	7	8
Critical Range	.1245	.1310	.1354	.1386	.1411	.1431	.1448

Duncan Grouping	Mean	N	GROUP
A	3.15645	20	Submarginal Forest
B	3.02638	20	Mossy Forest
C B	2.92126	20	OLD GROWTH FOREST-HIGH
C	2.85875	20	Grassland
C	2.84532	20	OLD GROWTH FOREST-LOW
C	2.83362	20	RESIDUAL FOREST
C	2.79187	20	Brushland
D	0.77815	20	Open Land

---------- SLOPE + ASPECT CLASS=64 ----------

Number of observations in by Group = 160

Dependent Variable: LRADAR

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	7	54.286248	7.755178	55.04	0.0001
Error	152	21.417462	0.140904		
Corrected Total	159	75.703710			

R-Square	C.V.	Root MSE	LRADAR Mean
0.717088	15.19695	0.3754	2.4701

Source	DF	Type III SS	Mean Square	F Value	Pr > F
GROUP	7	54.286248	7.755178	55.04	0.0001

Duncan's Multiple Range Test for variable: LRADAR

Alpha= 0.05 df= 152 MSE= 0.140904

Number of Means	2	3	4	5	6	7	8
Critical Range	.2345	.2468	.2551	.2611	.2658	.2696	.2728

Duncan Grouping	Mean	N	GROUP
A	2.7838	20	Brushland
A	2.7755	20	Submarginal Forest
A	2.7686	20	OLD GROWTH FOREST-HIGH
A	2.7455	20	OLD GROWTH FOREST-LOW
A	2.7361	20	Mossy Forest
A	2.7132	20	RESIDUAL FOREST
B	2.2426	20	Grassland
C	0.9950	20	Open Land

---------- SLOPE + ASPECT CLASS=65 ----------

Number of observations in by Group = 272

Dependent Variable: LRADAR

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	7	7.9149761	1.1307109	11.08	0.0001
Error	264	26.9397372	0.1020445		
Corrected Total	271	34.8547134			

R-Square	C.V.	Root MSE	LRADAR Mean
0.227085	11.51828	0.3194	2.7734

Source	DF	Type III SS	Mean Square	F Value	Pr > F
GROUP	7	7.9149761	1.1307109	11.08	0.0001

Duncan's Multiple Range Test for variable: LRADAR

Alpha= 0.05 df= 264 MSE= 0.102044

Number of Means	2	3	4	5	6	7	8
Critical Range	.1526	.1606	.1660	.1699	.1730	.1755	.1776

Duncan Grouping	Mean	N	GROUP
A	3.06386	34	Grassland
B	2.88646	34	OLD GROWTH FOREST-LOW
B	2.81806	34	Submarginal Forest
B	2.80273	34	Brushland
B	2.75012	34	OLD GROWTH FOREST-HIGH
B	2.73173	34	Mossy Forest
B	2.71746	34	RESIDUAL FOREST
C	2.41649	34	Open Land

---------- SLOPE + ASPECT CLASS=66 ----------

Number of observations in by Group = 160

Dependent Variable: LRADAR

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	7	70.861304	10.123043	275.33	0.0001
Error	152	5.588608	0.036767		
Corrected Total	159	76.449912			

R-Square	C.V.	Root MSE	LRADAR Mean
0.926898	7.577553	0.1917	2.5305

Source	DF	Type III SS	Mean Square	F Value	Pr > F
GROUP	7	70.861304	10.123043	275.33	0.0001

Duncan's Multiple Range Test for variable: LRADAR

Alpha= 0.05 df= 152 MSE= 0.036767

Number of Means	2	3	4	5	6	7	8
Critical Range	.1198	.1261	.1303	.1334	.1358	.1377	.1393

Duncan Grouping	Mean	N	GROUP
A	2.86736	20	OLD GROWTH FOREST-LOW
B A	2.82076	20	Submarginal Forest
B A	2.81143	20	RESIDUAL FOREST
B A	2.81088	20	Brushland
B A	2.80334	20	OLD GROWTH FOREST-HIGH
B C	2.68908	20	Mossy Forest
C	2.66275	20	Grassland
D	0.77815	20	Open Land

---------- SLOPE + ASPECT CLASS=67 ----------

Number of observations in by Group = 320

Dependent Variable: LRADAR

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	7	3.8033117	0.5433302	12.46	0.0001
Error	312	13.6063095	0.0436100		
Corrected Total	319	17.4096213			

R-Square	C.V.	Root MSE	LRADAR Mean
0.218460	7.138763	0.2088	2.9253

Source	DF	Type III SS	Mean Square	F Value	Pr > F
GROUP	7	3.8033117	0.5433302	12.46	0.0001

Duncan's Multiple Range Test for variable: LRADAR

Alpha= 0.05 df= 312 MSE= 0.04361

Number of Means	2	3	4	5	6	7	8
Critical Range	.0919	.0967	.1000	.1023	.1042	.1057	.1070

Duncan Grouping	Mean	N	GROUP
A	3.13697	40	Mossy Forest
B	2.96696	40	OLD GROWTH FOREST-HIGH
B	2.96666	40	Open Land
B	2.96376	40	RESIDUAL FOREST
B	2.90248	40	Brushland
B	2.87039	40	OLD GROWTH FOREST-LOW
B	2.86535	40	Grassland
C	2.72979	40	Submarginal Forest

---------- SLOPE + ASPECT CLASS=68 ----------

Number of observations in by Group = 320

Dependent Variable: LRADAR

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	7	13.334594	1.904942	34.00	0.0001
Error	312	17.481610	0.056031		
Corrected Total	319	30.816204			

R-Square	C.V.	Root MSE	LRADAR Mean
0.432714	7.934972	0.2367	2.9831

Source	DF	Type III SS	Mean Square	F Value	Pr > F
GROUP	7	13.334594	1.904942	34.00	0.0001

Duncan's Multiple Range Test for variable: LRADAR

Alpha= 0.05 df= 312 MSE= 0.056031

Number of Means	2	3	4	5	6	7	8
Critical Range	.1041	.1096	.1133	.1160	.1181	.1199	.1213

Duncan Grouping	Mean	N	GROUP
A	3.34717	40	Open Land
B	3.21565	40	Brushland
C	3.05486	40	RESIDUAL FOREST
D C	2.99903	40	OLD GROWTH FOREST-HIGH
D E	2.93220	40	Mossy Forest
F E	2.82975	40	OLD GROWTH FOREST-LOW
F	2.74383	40	Submarginal Forest
F	2.74232	40	Grassland